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PANEL SYSTEM OF COAL MINING
A GRAPHICAL STUDY OF PERCENTAGE OF EXTRACTION

BY

C. M. YOUNG

ILLINOIS COAL MINING INVESTIGATIONS COÖPERATIVE AGREEMENT

(THIS REPORT WAS PREPARED UNDER A COÖPERATIVE AGREEMENT BETWEEN THE ENGINEERING EXPERIMENT STATION OF THE UNIVERSITY OF ILLINOIS, THE ILLINOIS STATE GEOLOGICAL SURVEY, AND THE U. S. BUREAU OF MINES)

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PANEL SYSTEM OF COAL MINING
A GRAPHICAL STUDY OF PERCENTAGE OF EXTRACTION

I. Introduction

1. *Reasons for the Investigation.*—In 1917 an investigation* of the percentages of coal extracted and lost in Illinois and in other bituminous coal mining districts showed that the percentage obtained is less than is commonly believed. The conclusions reached in the earlier investigation naturally led to the study of the panel system to determine the greatest possible extraction with different dimensions of workings.

2. *Other Investigations.*—Investigations of a similar nature have been made to determine the relation between dimensions of workings and amounts of extraction. Special mention should be made of the work of J. C. Quade, G. E. Lyman, and J. C. Gibson, whose methods are described on pages 46, 66, and 70. So far as is known, however, no study of the panel system in general with regard to the percentage of extraction and the change of this percentage with change of dimensions of workings has hitherto been made.

3. *Acknowledgments.*—The work of the Illinois Coal Mining Investigations is carried on under the direction of Professor H. H. Stoek, head of the Department of Mining Engineering, University of Illinois; F. W. De Wolf, Chief, State Geological Survey Division; and G. S. Rice, Chief Mining Engineer, U. S. Bureau of Mines. Professor Stoek has been especially helpful in carefully revising the manuscript.

4. *Summary.*—The investigation shows that the highest extraction which can possibly be attained under the conditions assumed, with rooms 300 feet long and 30 feet wide on 50-foot centers, is only 57.05 per cent. Even if the improbable ratio of room to pillar width

*Young, C. M., "Percentage of Extraction of Bituminous Coal with Special Reference to Illinois Conditions." Illinois Coal Mining Investigations, Univ. of Ill. Eng. Exp. Sta., Bul. 100, 1917.

of 4 to 1 (40-foot rooms on 50-foot centers) is assumed, the highest attainable extraction is 68.48 per cent. No better results than these can be reached unless the amount of coal left in room pillars or in barrier pillars is reduced. As a matter of fact, the average extraction throughout the State is not more than 50 per cent and in those parts where coal is thickest and lies at greatest depth, the extraction will not average so much. The lowest extractions are due in part to the leaving of top coal; thus the actual extraction in some districts is lower than that indicated by calculation on an area basis.

The percentage of extraction increases with the increase of ratio between room width and pillar width, with length of rooms and with number of rooms per entry, but the diagrams showing the effect of changes of dimensions on percentages of extraction indicate that, except in the case of ratio of room width to pillar width, very nearly the maximum effect of these changes has been reached by the dimensions considered, *i. e.*, room length from 200 to 300 feet, room width from 20 to 40 feet, number of rooms per entry from 8 to 24. Further increase of length of rooms or of number of rooms per entry would not materially increase the percentage of extraction.

The percentage of extraction could be further increased by increase of room width in relation to pillar width, but it is only rarely that a ratio of even 4 to 1 can be used without the production of squeezes. The conclusion is, therefore, warranted that the extraction under a panel system of mining, which relies upon coal left in the ground for the support of the overburden, cannot be greater than about 68 per cent unless a smaller amount of coal is left in the form of barrier pillars than is assumed in this investigation.

5. *Reasons for Low Extraction.*—There are two essential reasons for low extraction. The first is the leaving of top coal, because the roof needs support or because the bed is too thick for convenient mining of the whole thickness. Such losses occur principally in the thick coal of the southern part of the State. When some support for the roof is necessary and when it can be furnished by coal left in place at less cost than by artificial means, the leaving of coal is justified, commercially, though such loss may still be criticized from the standpoint of conservation. In some places, however, the thickness of coal left is much greater than is necessary to support the roof, and it is probable that a considerably larger amount of the coal might be extracted at a cost which would allow a profit on the top coal mined.

The second reason for low extraction lies in the method of mining which depends upon coal, left in the form of pillars, to support overlying material. The use of coal for such support may be considered: first, for the support of the immediate top until a place has been worked out, and secondly, for the permanent support of the overburden to prevent subsidence of the surface.

In the first case large pillars would commonly be unnecessary and the ratio of room width to pillar width might be large. Under this case may be considered such operations as those in Fulton County, discussed in Appendix I, where no attempt is made at permanent support of the surface, and where coal left in pillars may be considered as serving the same purpose as props. Pillars which are 8 feet wide near the entry are tapered to almost nothing at the end; yet these pillars serve their purpose of support to the immediate top until the coal has been worked out. Under such circumstances it is possible to extract from 70 to 80 per cent of the coal, but such results would be unattainable in thick coal because the strength of a pillar decreases rapidly as its height increases, and consequently greater pillar width would be necessary to furnish the support needed.

The second case is that of the use of coal in the form of pillars as a permanent support for the overburden, and this use constitutes the principal reason for low extraction. A much higher percentage of coal might be obtained if the surface were allowed to subside. Under present conditions, however, this practice is not often considered practical, especially where ownership of the coal and the surface is separate, because the operator is often compelled to pay very high damages for any disturbance of the surface.

While no general rule can be stated for the determination of the dimensions of pillars and of the ratio of pillar area to room area necessary for the permanent support of the surface at a given depth, it is known that the relative area of pillars must be made greater as the depth increases. Experience in Illinois shows that the surface cannot be permanently sustained over the deeper and thicker beds of the State unless about half of the coal is left. This statement is true in general for Districts V, VI, and VII, of the Illinois Coal Mining Investigations, which include bed 5 in Saline and Gallatin counties and nearly all mines in the No. 6 coal.

No high percentage of extraction is possible without subsidence of the surface unless the space left by the coal is filled, probably by washing fine material into the mine through pipes. Illinois mines are

in general nearly level and it would be difficult to transport the filling material along the entries by means of water; also the removal of the water would be difficult and expensive. For these reasons the method appears at present to be impractical in Illinois; therefore if high extraction is to be obtained subsidence must be expected and controlled as is being successfully done in some districts where extraction of more than 90 per cent is customary.

II. Advantages of Greater Extraction

The principal advantages of higher extraction may be summarized as follows:

6. *Investment per Ton of Total Output.*—If the amount of coal extracted could be increased from 50 to 100 per cent, the investment, per ton of total coal produced for surface plants, shafts, entries, etc., would be reduced by half because twice as much coal would be handled with the equipment. Maintenance charges, however, would not be similarly reduced since the colliery would be in operation for twice as long if the same territory were involved. The cost per ton of coal in the ground would be decreased by one-half when the coal is purchased in fee, and where it is leased on royalty the owner of the land would receive twice as much as he formerly received.

7. *Cost of Haulage.*—The cost per ton for moving the coal from the working place to the shaft would be decreased, because the average length of haul would be only half as much as with 50 per cent extraction. Twice as much coal would be hauled through the entries, so that the cost per ton of coal for maintaining entries would be lessened. Since the element of time is also involved, it is not possible to say that the cost for maintenance would be reduced by 50 per cent.

8. *Cost of Ventilation.*—The average distance from the shaft of places to be ventilated being only half as much as with 50 per cent extraction, the expense of ventilation would be decreased. Ventilation would be simplified, because worked-out places would cave and would require no attention except the provision of bleeders or of seals.

To summarize, the cost per ton of total coal for all installations and excavations which would not need renewal because of the increased time of service would be reduced by 50 per cent. In operations whose costs are affected by the distance from the shafts to the point of production, the costs would be reduced in proportion to the effect of the distance. While it cannot be expected that an extraction of 100 per cent will be obtained, an extraction of 90 per cent should not be

difficult from an engineering standpoint, and the economies resulting would be in proportion to the increase.

9. *Efficiency of Supervision.*—Appreciation of the need of thorough supervision to preserve mines in working condition and to prevent accidents is increasing, but under present mining practice the visits to a working place can be made more frequent only by increasing the supervising force, thus adding to the cost of coal. With greater extraction the concentration of workings would eliminate a part of the time now lost in travel, and thus would help to solve the problem of increased supervision.

10. *Prevention of Waste.*—The greatest ultimate advantage of higher extraction would be the increase of the available reserves of coal. At present this advantage is largely overlooked, because the reserves of coal of the quality and thickness now mined are sufficient for many years. Unfortunately, however, it is the best coal and that easiest to produce which is being lost, and the coal which will be available when the reserves are exhausted will certainly be more costly and perhaps not so good. Even if the question of reserves is neglected because no immediate exhaustion is possible, it is a subject for great regret that a substance as valuable as coal should be unnecessarily lost.

There is no doubt of the ability of mining engineers to plan operations to get high extraction. The methods are well known and are employed with great advantage and without great difficulty in some districts, and there is no reason to doubt their success in Illinois. The problem is more one of immediate commercial advantage than one of engineering practice.

III. Principles Involved in High Extraction

High extraction requires the mining of pillar coal. Three principles are involved in the successful extraction of this coal: first, the strain on the roof above the rooms must not be great enough to cause the roof to fall before the pillar coal is removed; secondly, the strain on the pillars must not be great enough to cause squeezing; thirdly, additional strain on the pillars, due to pillar drawing, must be prevented by the breaking of the roof behind the retreating pillar face.

The fall of the roof can be prevented by making the room sufficiently narrow, or at least the strain can be decreased so that proper timbering will prevent falls. This does not necessarily involve low ratio of room width to pillar width. If the pillars are to be removed, however, they will necessarily be made large enough for convenient working. In some districts where pillar coal is successfully mined and where high extraction is reached, rooms are made very narrow and are, in fact, little more than openings for ventilation and for access to the pillar coal. Such extreme narrowness is necessary only under bad top, and rooms in most places in Illinois could probably be made 20 feet wide without interference with successful pillar work.

The strain on the pillars due to the weight of the overburden must be kept within the limits of strength of the pillars themselves and of the top and bottom. When the room coal is removed, the weight of the overlying material is transferred to the pillars and these must be made large enough to stand the strain without being crushed or pressed into the top or bottom.

When the extraction of the pillar coal is commenced at the end of the room, a part of the weight of the overburden above the portion removed is transferred to the remaining pillars, thus increasing the strain. This strain may be relieved by the breaking of the roof behind the retreating pillar face.

If enough coal is left in pillars to prevent crushing before pillar drawing begins, and if the strain is relieved by the breaking of the roof during pillar drawing, squeezes will be entirely prevented.

These three principles: rooms narrow enough for the support of the roof, pillars large enough to stand without crushing, and

relief of additional strain due to pillar drawing by the breaking of the roof, are successfully applied in some mining districts in this country. There is nothing in the physical conditions of the Illinois coal fields to indicate that the application of these principles is impossible or even unusually difficult.

IV. Method of Investigating the Percentages of Extraction

The object of the calculations hereinafter described was the determination of percentages of extraction when plans for the development of a mine are carefully made and all dimensions accurately followed. It was necessary to consider a hypothetical mine or a part of one consistently developed on some predetermined plan. The discussion has been confined to the panel system, because it represents the highest development reached in the extraction of coal by rooms and pillars. It is upon this system that all large modern mines in Illinois are projected.

The term *panel system* originally implied the isolation of a group of rooms, called a panel, from other such groups or panels, by a surrounding pillar of coal pierced on one side only by the room entries. The term is now frequently applied to a system in which the room entries do not terminate in the panel but are driven through to the next cross entry, the block of rooms thus being opened at both ends instead of only at one, the pillars between the ends of panels being omitted.

The present tendency in Illinois seems to be toward the adoption of a more nearly completely isolated panel than has been used though the fire pillars remaining are too narrow to resist squeezing. On this basis the values in the tables and diagrams given have been calculated. The assumed pillars between the ends of adjacent panels are, however, very thin and approximately the same values will be found if these pillars are omitted. The figures and diagrams will apply very closely to either form of the panel system.

11. *Basis of Calculation.*—In the following discussion extraction is calculated on the basis of area excavated instead of on that of tonnage produced. When the workings are of uniform height throughout the mine, the extraction on the basis of tonnage is proportional to that on the basis of area, but, if a portion of the coal is left at top or bottom as is frequently the case in thick coal and under a poor roof, the ratio of tonnage to area may vary in different parts of the mine. Whenever coal is left on the top or bottom, the extraction on a tonnage basis is less than that on an area basis. To get the per-

centage of extraction on a tonnage basis from that on an area basis, the latter should be multiplied by the ratio of thickness mined to the total thickness of the bed. In some parts of Illinois, for example, where the thickness of the coal is nine feet or more, only about seven feet of the coal is extracted. In such places the tonnage produced cannot be more than seven-ninths, or 78 per cent, of that indicated by the area excavated and is less if the thickness of the coal is greater than nine feet. This fact should be borne in mind in considering the percentages of extraction given in this bulletin. In other words these percentages are the maximum amounts of coal which it is possible to get with the given dimensions of workings without the gouging of pillars or the extraction of pillar coal on the retreat. As there is always some waste in mining, the extractions obtained in practice with similar dimensions may be expected to fall below those indicated in the tables. The amount of waste is variable, but it is doubtful if it is ever less than 5 per cent.

12. *Method of Computation.*—An area of 160 acres was selected as large enough to give sufficiently accurate results, and workings were laid out for this area. Since an area of nearly an acre is worked out per day in the larger mines, which produce 4000 tons, or more, per day as now operated in Illinois, it will be seen that 160 acres is only a small part of the tract developed by a single large mine; in fact it represents only about 160 days' work. Accordingly in planning the projection, no attempt was made to lay out 160 acres as a complete mine, but this small tract was assumed to be part of a larger district and was treated as if a square of 160 acres had been taken from the map of a large mine.

If the 160 acres had been developed by itself, one would naturally assume that the main entry was driven through the middle of the tract and that the cross entries were driven equal distances to each side. Instead of this assumption it was determined as a matter of simplification that the line of the ends of a series of panels driven from one cross entry should constitute one border, m - n, and the sides of a series of panels should constitute another border, n - o (Fig. 1).

In this 160-acre tract workings were laid out with different dimensions and the percentages of extraction for these different dimensions calculated. The room lengths chosen were 200 feet, 250 feet, and 300 feet. The numbers of rooms per entry chosen were 8, 12, 16,

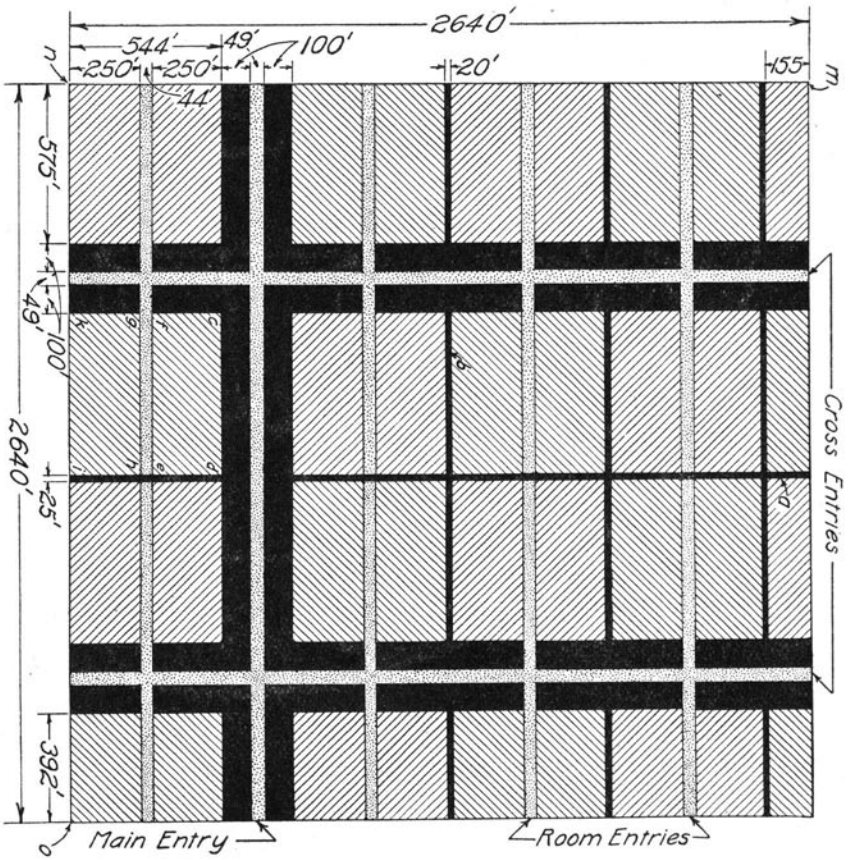

FIG. 1. MAP OF 160-ACRE TRACT SELECTED FOR INVESTIGATION

20, 24, and 28. The cases assumed include, of course, only a few of the many dimensions and numbers of rooms that may occur, but they show the effects of variation in dimensions and number.

For the first calculation it was assumed that all rooms should be 25 feet wide and driven on 50-foot centers. After the method had been developed for these dimensions, calculations were made for different room widths, namely, 20, 30, 35, and 40 feet. Other assumptions made with regard to various portions of the workings will be explained in the detailed consideration of the calculations of area and extraction.

No allowance was made for a barrier pillar around the tract

since the barrier pillar left around the borders of a mine constitutes only a very small percentage of the total area, and the proportion which would be chargeable to an area of 160 acres would be insignificant.

One result of the limitation of the area is the occurrence of certain irregularities in the percentages of area occupied by different portions of the workings and in the percentages of extraction. These irregularities would not be found if a larger tract were under consideration. They will be explained in the discussion of the diagrams showing areas and percentages of extraction (Figs. 4 to 9).

The dimensions assumed are as follows:

	Feet
Entry width	12
Main entry pillar	25
Cross entry pillar	25
Room entry pillar	20
Entry cross-cut width	12
Entry cross-cut centers	72
Barrier pillars	100
Pillars at sides of panels	20
Pillars at ends of panels	25
Room neck, width	18
Room neck, length	12
Distance from entry rib to point where room reaches full width	18
Room cross-cut width	18

The constant quantities in the calculations are the dimensions of the tract under consideration, the widths of entries and entry pillars, the spacing and width of entry cross-cuts and room cross-cuts, the dimensions of room necks, and the widths of barrier pillars and of pillars at sides and ends of panels. The variables are the length of rooms, the width of rooms, and the number of rooms per panel. Changes in these variables involve changes in the percentages of area occupied by different portions of the workings and in the percentage of extraction in the portions occupied by rooms and pillars.

13. *Method of Procedure.*—The method of procedure involved: first, the determination of the percentage of coal won or lost in any portion of the workings, such as rooms and pillars, and barriers, and secondly, the determination of the percentage of the entire area

occupied by this portion. A calculation was made, for example, of the percentage of extraction inside a panel and then of the percentage of the total area occupied by panels. A summation of the extractions in different workings gave the total extraction.

Three classes of workings are considered: (1) rooms and pillars, (2) entries, and (3) pillars outside the panels. These divisions are taken up separately and in order.

In determining the area excavated in the room and pillar area of the panel, that is, the area of the panel mined out with the exception of the room entry, *cdef* and *ghik*, Fig. 1, a calculation of the area of a single room and its cross-cuts was made. This area was multiplied by the number of rooms per panel, proper allowance being made for the fact that there is always one more room than pillars on an entry and that the total area of cross-cuts is calculated from the number of pillars. To calculate the area taken out per room the area lost at the neck was subtracted from the product of the width and the length of the room.

The forms and the dimensions of the room necks and cross-cuts are shown in Fig. 2. The area lost at the room neck in the case of a room 25 feet wide is

$$2 \times 3.5 \times \frac{18+12}{2} = 105 \text{ square feet}$$

In all cases it was assumed that cross-cuts were staggered and that the number of cross-cuts through any pillar was either one more or one less than that made through the adjoining pillars. Cross-cuts were so spaced that no working place would be driven more than 60 feet ahead of the air current. This arrangement gives an average of 1½ cross-cuts per pillar for the 200-foot rooms, and 2½ for the 250-foot rooms. This method of arranging cross-cuts is common but not universal. The percentage of area occupied by cross-cuts is small, however, and it makes little difference, so far as the percentage of extraction is concerned, whether the cross-cuts are assumed to be in a straight line or staggered. The area of cross-cuts per pillar in the case of the 250-foot room is

$$2.5 \times 18 \times 25 = 1{,}125 \text{ square feet}$$

The area of the rooms turned from one entry, with their cross-cuts, assuming 12 rooms per entry and a room length of 250 feet, is

$$12\,[(25 \times 250) - 105] + (11 \times 2.5 \times 18 \times 25) = 86{,}115 \text{ square feet}$$

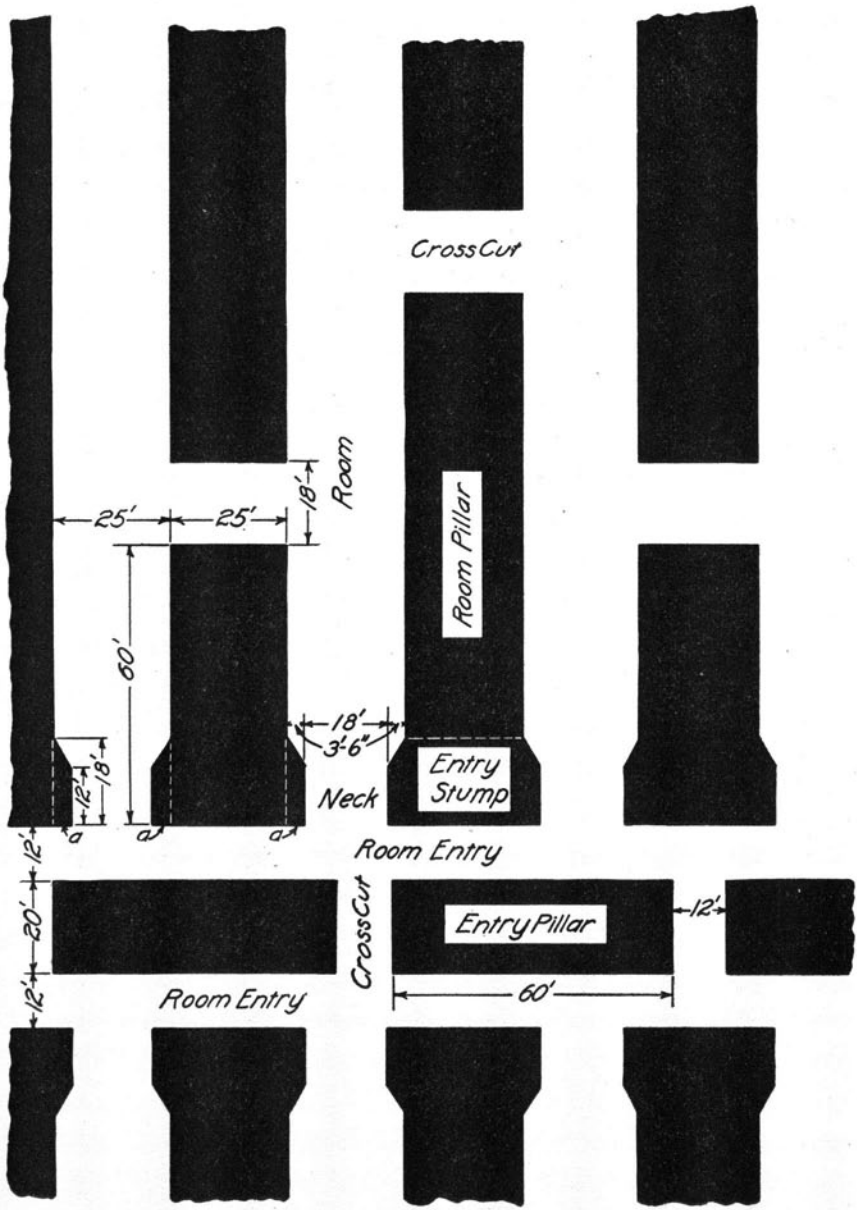

FIG. 2. ROOM ENTRY AND ROOM NECKS

In the following computations it is assumed that rooms are turned from both the room entries, and the area of the number of rooms and room cross-cuts in the panel is

$$2\times 86{,}115 = 172{,}230 \text{ square feet}$$

The area devoted to rooms and pillars in a panel of 12 rooms, 25 feet wide on 50-foot centers and 250 feet long, is

$$[24\times 25\times 250] + [22\times 25\times 250] = 287{,}500 \text{ square feet}$$

and the percentage of extraction is

$$\frac{172{,}230\times 100}{287{,}500} = 59.91 \text{ per cent}$$

14. *Lengths of Entries.*—The lengths of entries are obtained by measurement or by calculation. The length given in each case is that of the double entry, e. g., the length of the main entry is 2640 feet.

15. *Percentage of Extraction in Entries.*—With the following notation,

Le = length of entry
We = width of entry
n = number of entries (2 for double entry, 3 for triple entry)
Wp = width of entry pillar
Wc = width of cross-cuts
Cc = cross-cut centers

the percentage of extraction in any entry or group of entries is expressed by the formula:

$$\frac{[(n\times Le\times We) + (n-1)\,(\frac{Le}{Cc}\times Wc\times Wp)]\times 100}{(n\times Le\times We) + (n-1)\times Le\times Wp}$$

With the dimensions assumed on page 18, the percentage of extraction in room entries is

$$\frac{[(2\times 12) + (\frac{12}{72}\times 20)]\times 100}{44} = 62.12 \text{ per cent}$$

In the same way the percentage of extraction in main entry and cross entries is

$$\frac{[(2\times12)+(\frac{12}{72}\times25)]\times100}{49}=57.48 \text{ per cent}$$

The difference in extraction between the main and cross entries and the room entries is due to the differences in width of entry pillars.

The area extracted in the room entries inside the panel is equal to the area occupied by the entries and entry pillar multiplied by the percentage of extraction:

$$44\times575\times0.6212=15{,}716 \text{ square feet}$$

16. *Percentage of Extraction Inside the Panel.*—The total area extracted inside the panel is the sum of the areas of rooms with their cross-cuts and of the entries and their cross-cuts.

$$172{,}230+15{,}716=187{,}946 \text{ square feet}$$

and the percentage of extraction is

$$\frac{187{,}946\times100}{544\times575}=60.09 \text{ per cent}$$

in which 544 is the width of the panel and 575 the length.

17. *Percentage of the Total Area Occupied by Panels.*—In any restricted area, such as that under consideration, there will be in most instances a number of whole panels and parts of others which can be determined by plotting or by computation. In the case under consideration, which is illustrated in Fig. 1, there were 12 whole panels 544 by 575 feet, 3 parts of panels 155 by 575 feet, 1 part 155 by 392 feet, and 4 parts 544 by 392 feet. The total area of the panels was then:

	Square Feet
$12\times544\times575=$	3,753,600
$3\times155\times575=$	267,375
$155\times392=$	60,760
$4\times544\times392=$	852,992
	4,934,727

The total percentage of area occupied by panels is

$$\frac{4{,}934{,}727 \times 100}{6{,}969{,}600} = 70.80 \text{ per cent}$$

18. *Percentage of Total Area Extracted in All Panels.*—This is the product of the percentage of total area occupied by panels and the percentage of extraction in panels:

$$70.80 \times 0.6009 = 42.54 \text{ per cent}$$

19. *Entry Area Outside the Panels.*—A double main entry is assumed to be driven across the tract, its area being $2{,}640 \times 49 = 129{,}360$ square feet. In the case of the two double cross entries the width is the same, but the length is less by the width of the main entry from which the two cross entries are driven. The area of these two is

$$2 \times 2{,}591 \times 49 = 253{,}918 \text{ square feet}$$

The area devoted to the main entry was the same in all instances since only one main entry was assumed. The area of cross entries varied considerably as there were sometimes three cross entries, sometimes two and sometimes only one.

The area of room entries outside the panel is

$$16 \times 44 \times 100 = 70{,}400 \text{ square feet}$$

In the tract under consideration, illustrated in Fig. 1, there are no fractional widths of cross entry barriers to be considered and all the portions of room entries outside the panels are 100 feet long. In some other cases there were fractions of barrier pillars and therefore different lengths of room entries outside the panels.

The total area occupied by entries outside the panels is the sum of the areas of main entry, cross entries, and room entries with their entry pillars:

	Square Feet
Main entry	129,360
Cross entries	253,918
Room entries	70,400
	453,678

The area of the room entries and entry pillars inside the panels is

$$12\times44\times575 + 4\times44\times392 = 372{,}592 \text{ square feet}$$

20. *Percentage of Area Occupied by Entries.*—The percentages of total area occupied by entries are as follows:

Main entry . . . . . $\frac{129{,}360\times100}{6{,}969{,}600} = 1.86$ per cent

Cross entries . . . . . $\frac{253{,}918\times100}{6{,}969{,}600} = 3.64$ per cent

Room entries—outside panels . . . . $\frac{70{,}400\times100}{6{,}969{,}600} = 1.01$ per cent

Room entries—inside panels . . . . . $\frac{372{,}592\times100}{6{,}969{,}600} = 5.35$ per cent

The percentage of the total area occupied by room entries both outside and inside the panel is

$$1.01 + 5.35 = 6.36 \text{ per cent}$$

21. *Percentage of Total Area Extracted in Entries.*—To get the percentage of total area extracted in entries, the percentage of area occupied by the entry is multiplied by the calculated percentage of extraction, as follows:

	Percentage
Percentage of total area extracted in room entries inside panels	$5.35\times0.6212=3.32$
Percentage of total area extracted in room entries outside panels	$1.01\times0.6212=0.63$
Percentage of total area extracted in cross entries .	$3.64\times0.5748=2.09$
Percentage of total area extracted in main entry .	$1.86\times0.5748=1.07$
Total percentage extracted in entries . .	7.11

22. *Summary of Percentages of Extraction.*—The extraction in the different parts of the mine may then be summarized as follows:

	Percentage
Panels	42.54
Room entries—outside panels	0.63
Cross entries	2.09
Main entry	1.07
Total	46.33

23. *Area Left in Pillars Outside the Panels.*—The only area remaining to be considered is that occupied by barrier pillars and pillars at sides and ends of panels. As it is assumed that this pillar coal is entirely lost the only thing to be considered is the area and the percentage of total area occupied by the pillars. If in any case it is to be assumed that some of this coal is to be saved, the amount thus extracted may be found by multiplying the area of the pillars by the percentage of extraction.

It is, of course, not always true that all the coal thus left is lost, and theoretically this is seldom the case, as it is generally intended that a large part of the coal left, especially in barrier pillars, will be extracted later. In some coal mining districts this coal is extracted, but in the Illinois fields very little of the barrier coal is mined; consequently it seems better to assume complete loss of this coal rather than an arbitrary percentage of recovery.

In the case of each entry barrier the area is the length of the barrier multiplied by its width, minus the area of the entries which extend through it but including the entry pillar. The area of the main entry barrier pillars, as thus defined, is

$$2\times100\times2640 - [(8\times100\times12) + (4\times25\times12)] = 517{,}200 \text{ square feet}$$

The percentage of the total area devoted to main entry barrier pillars is

$$\frac{517{,}200\times100}{6{,}969{,}600} = 7.42 \text{ per cent}$$

This percentage is unusually high because of the small area considered. In the case of a square area of 5,000 acres with one main entry with barrier pillars 100 feet wide, the percentage of area occupied by the main entry barriers is about 1.3 per cent.

The length of the cross entry barrier pillars is the distance across the tract minus the width of the main entry with its two barrier pillars. The area is

$$4\times100(2640-249) - [(32\times100\times12) + (16\times20\times12)] = 914{,}160 \text{ square feet}$$

The percentage of total area is

$$\frac{914{,}160\times100}{6{,}969{,}600} = 13.12 \text{ per cent}$$

The area left in pillars at the ends of panels is, in the cases assumed

$$25 \times (2640 - 249) = 59{,}775 \text{ square feet}$$

The percentage of the total area occupied by these pillars is

$$\frac{59{,}775 \times 100}{6{,}969{,}600} = 0.86 \text{ per cent}$$

The area of the pillars left at the sides of panels is, in the case assumed

$$(9 \times 20 \times 575) + (3 \times 20 \times 392) = 127{,}020 \text{ square feet}$$

The percentage of total area occupied is

$$\frac{127{,}020 \times 100}{6{,}969{,}600} = 1.82 \text{ per cent}$$

The sum of the various items of loss in pillars outside the panels and entries is

Main entry barrier	7.42
Cross entry barrier	13.12
Total in entry barriers	20.54
In pillars at ends of panels	0.86
In pillars at sides of panels	1.82
Total left in pillars outside the panels	23.22

24. *Percentages of Extraction with Different Room Widths.*— In computing the percentage of total extraction with various other room widths considered: viz., 20, 30, 35, and 40 feet the dimensions of room centers were kept unchanged at 50 feet. It is recognized that this would not be the practice, but a change of room centers would have so complicated the problem as to require a much longer period for the attainment of results. The method of calculation has been clearly indicated and it is possible, by selecting room and pillar widths of the proper ratio in Tables 4, 5, and 6 to obtain close approximations to the percentages of extraction and loss with any widths of room and pillar desired.

It was assumed that the length of the panels and the percentage of total area devoted to panels for each number of rooms per entry

were not changed by these alterations in room and pillar dimensions. This assumption is not strictly true, since the length of the panel varies with the room width; for example, a panel of eight 40-foot rooms to the entry is 390 feet long instead of the 375 feet assumed. The discrepancies are greatest in the instances of widest rooms, because the difference between real panel length and assumed panel length is greatest. There are two errors which partially neutralize each other, and it was found by computation for the extreme cases that the final errors were very small. In the first place if the panel is actually longer than is assumed, the percentage of extraction in the panel is less than that computed. In the second place if the panel is longer than assumed, the total area occupied by panels is greater than that computed. The errors for the first and the last figures in the various columns of Table 4 are as follows: In the column for 20-foot rooms the first figure is 0.05 too high and the last figure is 0.29 too low; in the column for 25-foot rooms the figures are correct; in the column for 30-foot rooms the first figure is 0.05 too low and the last figure 0.04 too high; in the column for 35-foot rooms the first figure is 0.11 too low and the last figure 0.25 too high; in the column for 40-foot rooms the first figure is 0.15 too low and the last figure 0.67 too high. The other figures in each column have errors intermediate between those of the first and last figures. The errors all being less than one per cent, it is apparent that this method of calculation is sufficiently accurate for all purposes for which it is likely to be used, as departures from the projected method of working will account for greater differences between the actual and the computed output than the small errors in the tables.

25. *Tables and Diagrams.*—For convenience in reference the values obtained by the methods described in the preceding pages have been collected in Tables 1-7, which give the percentages of total area occupied by different classes of workings, the percentages of extraction in these different classes, the percentages of total area excavated in the different classes of workings, the percentage of total area won, the lengths of entries and the amounts of narrow work.

Most of the facts given in the tables are shown graphically in Figs. 3 to 9. These figures permit comparison between the results obtained by the use of different dimensions of workings.

For 25-foot rooms, Table 1 shows in column 3 the percentage of

TABLE 1

EXTRACTION IN PANELS

25-FOOT ROOMS

Length of Rooms (Feet)	Number of Rooms per Room Entry	Percentage of Extraction in Room and Pillar Area[1]	Percentage of Extraction inside the Panel	Percentage of Total Area Occupied by Panels	Percentage of Total Area Extracted in Panels
200	8	58.51	58.87	62.17	36.60
	12	57.54	57.99	70.20	40.71
	16	57.06	57.56	77.09	44.37
	20	56.78	57.31	78.45	44.96
	24	56.60	57.15	78.45	44.83
	28	56.47	57.03	79.28	45.21
250	8	60.89	60.92	62.71	38.20
	12	59.91	60.09	70.80	42.54
	16	59.45	59.67	77.76	46.40
	20	59.19	59.43	79.14	47.03
	24	59.01	59.27	79.13	46.90
	28	58.89	59.15	79.97	47.30
300	8	62.39	62.37	63.25	39.45
	12	61.49	61.53	71.41	43.94
	16	61.05	61.12	78.43	47.94
	20	60.80	60.88	79.81	48.59
	24	60.63	60.73	79.81	48.47
	28	60.51	60.62	80.65	48.89

[1]Room and pillar area shown by hatching in Fig. 1.

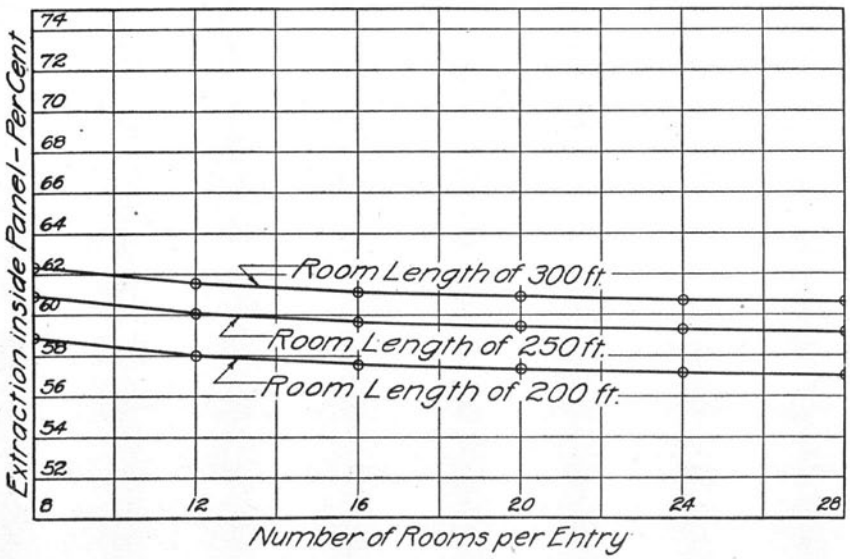

FIG. 3. PERCENTAGE OF EXTRACTION INSIDE THE PANEL FOR ROOMS 250 FEET LONG, 25 FEET WIDE, ON 50-FOOT CENTERS

extraction in the room and pillar area obtained with each length of room and each number of rooms per entry; in column 4 the total percentage of extraction inside the panel, that is, the sum of the extraction in rooms and room cross-cuts, and in room entries; in column 5 the percentage of the total area included in panels; and in column 6 the percentage of the total area extracted in panels. The percentage extracted in the panels plus the percentage extracted in the entries outside the panels gives the total percentage of extraction.

The values in column 4 of Table 1, the percentage of extraction inside the panel for rooms 25 feet wide, are illustrated by Fig. 3. For a given width of room and pillar the percentage of extraction inside the panel decreases somewhat as the number of rooms per entry increases, because the proportion of the total panel area remaining in pillars increases as the number of rooms increases and the percentage of extraction correspondingly decreases. With only two rooms and one pillar approximately 1/3 of the coal is left in the pillar, while with the 10 rooms and 9 pillars $\frac{9}{19}$ remain and with 20 rooms and 19 pillars $\frac{19}{39}$ remain.

The values in column 5 of Table 1 are illustrated in Fig. 4 which shows the percentage of total area included in panels for 25-foot rooms, 200 feet, 250 feet, and 300 feet long respectively, and for 8, 12, 16, 20, 24, and 28 rooms per entry. These diagrams show that the percentage of area devoted to panels increases with the length of the room and the number of rooms per entry. The increase is especially rapid for the smaller number of rooms per entry and comparatively small for the larger number of rooms per entry.

It will be noticed that there is a reversal in the direction of the lines at 24 rooms per entry shown in the broken lines based on the figures in the table, and that there is no corresponding change in direction of the diagrams for percentage of extraction inside the panel. These facts show that the drop in the diagrams of total extraction (Fig. 6) at 24 rooms per entry is due to the irregularity of the increase of percentage of total area included in panels, which in turn is due to the limited area considered. The solid lines (Figs. 4 and 6) show the positions when a large area is considered, and the same results are reached by calculation for 25 rooms per entry.

It will also be noticed that there is a comparatively rapid change in the direction of the lines when there are about 16 rooms per panel. This fact indicates that with 16 rooms per panel, or less, the percent-

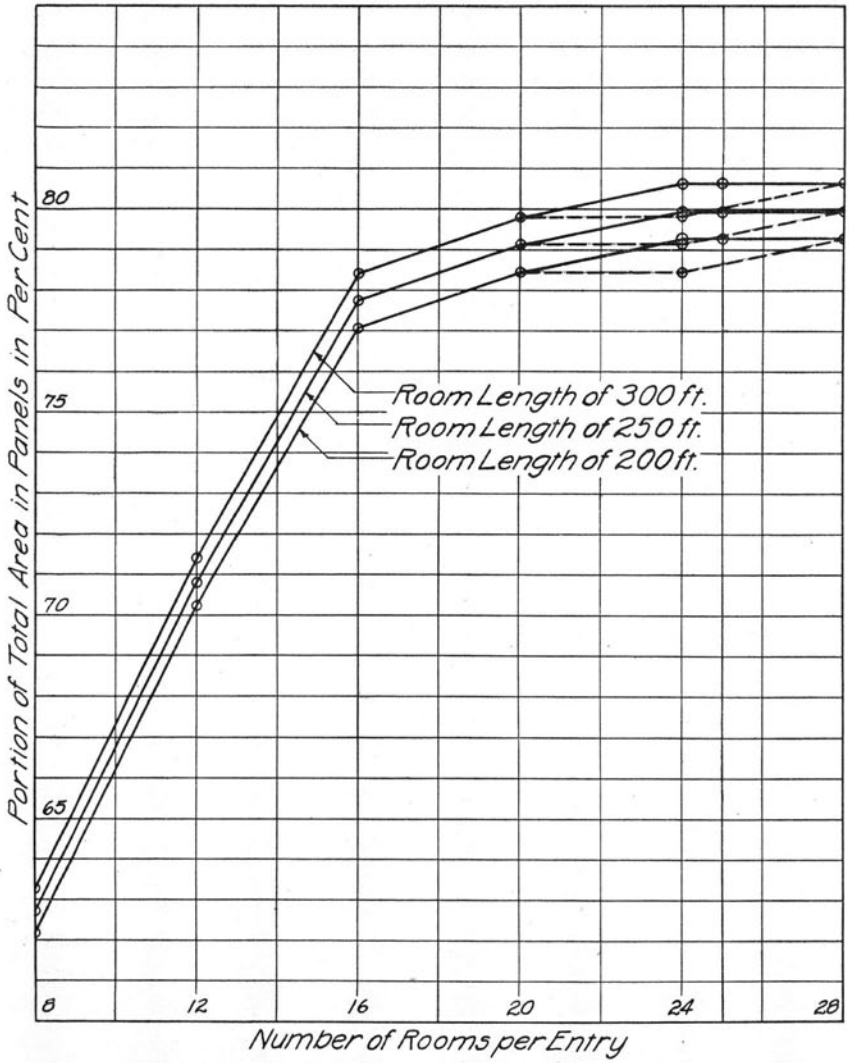

FIG. 4. PERCENTAGE OF TOTAL AREA INCLUDED IN PANELS FOR ROOMS 25 FEET WIDE, ON 50-FOOT CENTERS

age of area occupied by panels increases rapidly with the number of rooms per entry. For 16 rooms, or more, the increase is slow. This change also shows as does the diagram for total percentage of extraction, that this percentage increases comparatively rapidly with the

increase of number of rooms per entry to about 16 and that after this number is reached the rate of increase is small.

TABLE 2

EXTRACTION IN ENTRIES

Length of Rooms (Feet)	Number of Rooms per Room Entry	Percentage of Total Area Occupied by Entries					Percentage of Total Area Extracted in Entries			
		Main Entry	Cross Entry	Room Entry		Total	Main Entry	Cross Entry	Room Entry	Total
				Outside Panel	Inside Panel					
200	8	1.86	5.46	1.79	5.92	15.03	1.07	3.14	4.79	9.00
	12	1.86	3.64	1.26	6.68	13.44	1.07	2.09	4.93	8.09
	16	1.86	1.82	0.76	7.34	11.78	1.07	1.05	5.03	7.15
	20	1.86	1.82	0.63	7.47	11.78	1.07	1.05	5.03	7.15
	24	1.86	1.82	0.63	7.47	11.78	1.07	1.05	5.03	7.15
	28	1.86	1.82	0.63	7.55	11.86	1.07	1.05	5.08	7.20
250	8	1.86	5.46	1.43	4.74	13.49	1.07	3.14	3.83	8.04
	12	1.86	3.64	1.01	5.35	11.86	1.07	2.09	3.95	7.11
	16	1.86	1.82	0.61	5.87	10.16	1.07	1.05	4.02	6.14
	20	1.86	1.82	0.51	5.97	10.16	1.07	1.05	4.03	6.15
	24	1.86	1.82	0.51	5.97	10.16	1.07	1.05	4.03	6.15
	28	1.86	1.82	0.51	6.04	10.23	1.07	1.05	4.07	6.19
300	8	1.86	5.46	1.43	4.74	13.49	1.07	3.14	3.83	8.04
	12	1.86	3.64	1.01	5.35	11.86	1.07	2.09	3.95	7.11
	16	1.86	1.82	0.61	5.87	10.16	1.07	1.05	4.02	6.14
	20	1.86	1.82	0.51	5.97	10.16	1.07	1.05	4.03	6.15
	24	1.86	1.82	0.51	5.97	10.16	1.07	1.05	4.03	6.15
	28	1.86	1.82	0.51	6.04	10.23	1.07	1.05	4.07	6.19

Table 2 gives the percentage of total area occupied by entries and the percentage of total area extracted in entries, all for rooms 25 feet wide. Column 3 gives the percentage of total area in the main entry, column 4 the percentage of total area in the cross entries, column 5 the percentage of total area in the room entries outside the panel, column 6 the percentage of total area in the room entries inside the panel, and column 7 the total percentage of area occupied by entries. Column 8 gives the percentage of total area extracted in main entry, column 9 the percentage extracted in cross entries, column 10 the percentage extracted in room entries, and column 11 the total percentage of area extracted in entries.

The values in Table 2 are illustrated by Fig. 5 which shows the percentage of total area occupied by entries, including the entry pillars, for different numbers of rooms per entry and different lengths of rooms. The diagrams are drawn for 25-foot rooms, but, as shown in the discussion of the methods of calculation, they would be only slightly changed if different room widths were considered.

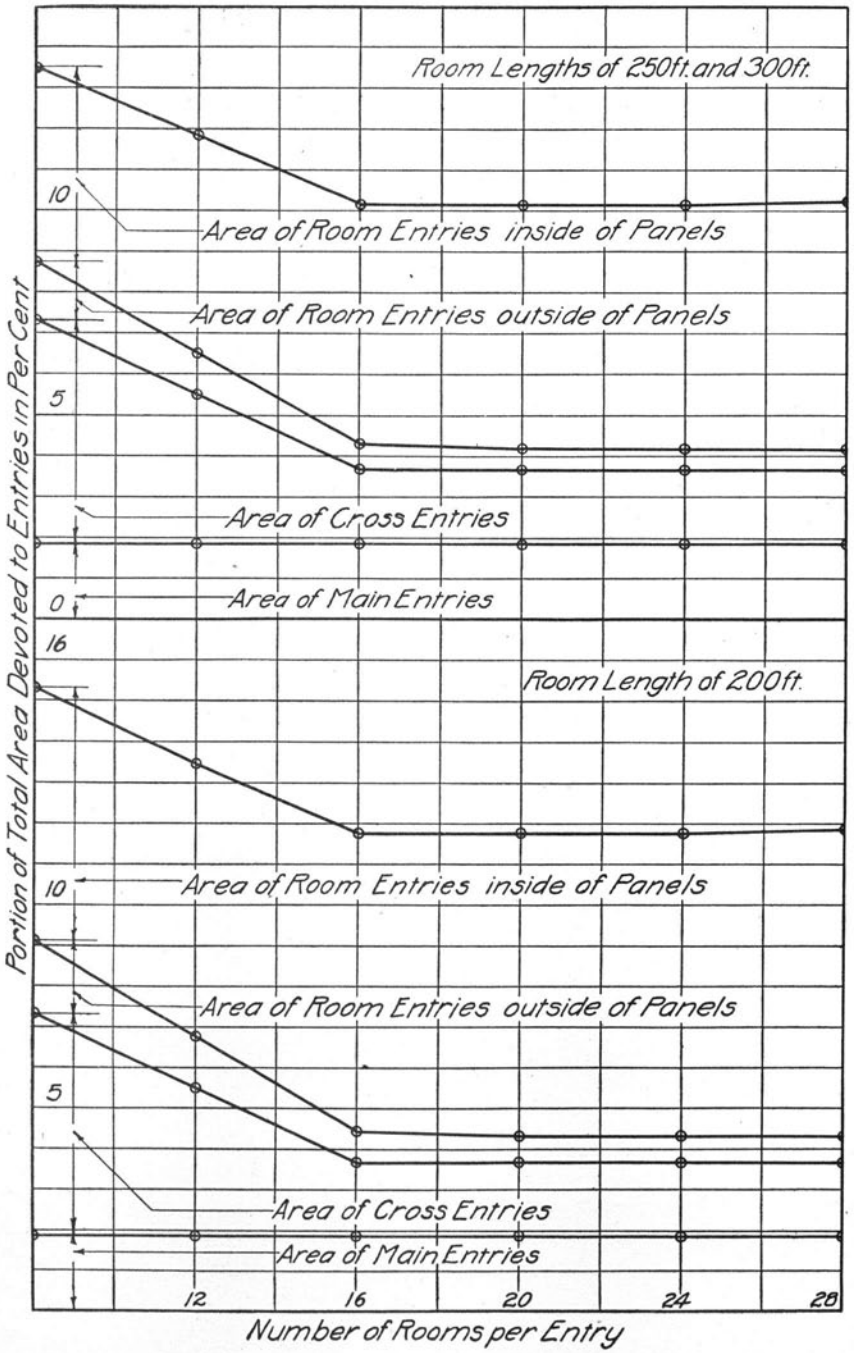

FIG. 5. PERCENTAGE OF TOTAL AREA OCCUPIED BY ENTRIES FOR ROOMS 25 FEET WIDE, ON 50-FOOT CENTERS

Column 3 of Table 3 shows the amounts of narrow work in entries. Columns 4, 5, 6, and 7 give respectively the length of main

TABLE 3

LENGTH OF ENTRIES AND YARDS OF NARROW WORK

Length of Rooms (Feet)	Number of Rooms per Room Entry	Yards of Narrow Work	Length of Double Entries in Feet[1]			
			Main Entry	Cross Entry	Room Entry	Total
200	8	17192	2640	7773	12215	22628
	12	15488	2640	5182	12585	20407
	16	13707	2640	2591	12830	18061
	20	13707	2640	2591	12830	18061
	24	13707	2640	2591	12830	18061
	28	13804	2640	2591	12955	18186
250	8	15333	2640	7773	9772	20185
	12	13591	2640	5182	10068	17889
	16	11752	2640	2591	10264	15495
	20	11771	2640	2591	10264	15495
	24	11771	2640	2591	10264	15495
	28	11848	2640	2591	10364	15595
300	8	15333	2640	7773	9772	20185
	12	13591	2640	5182	10068	17889
	16	11752	2640	2591	10264	15495
	20	11771	2640	2591	10264	15495
	24	11771	2640	2591	10264	15495
	28	11848	2640	2591	10364	15595

[1]These lengths refer to pairs of entries, not to single entries: i. e., they represent haulage distances along the entries. The total length of narrow work for which yardage is paid is therefore double the length given, plus the sum of the lengths of cross-cuts.

entries, cross entries, room entries and total entries, in all cases without entry cross-cuts. It should be noted that these are the lengths of double entries and not of single entries; for example, the length of the main entry, 2640 feet, is the distance across the tract.

The total cross entry length does not vary with the length of rooms, but decreases with the increase in the number of rooms per entry. This decrease is actually more regular than is indicated, because the table is for a small tract in which a cross entry is occasionally forced outside the boundary by increase of number of rooms per entry.

In the tract considered the total room entry length is the same for 250-foot and 300-foot rooms, but is greater for 200-foot rooms. If a large area were considered, the lengths for the 250-foot and 300-foot rooms would not coincide, but the length for the 250-foot rooms would lie between those of the 200-foot and 300-foot rooms. The total length of room entries increases slightly as the number of rooms per entry increases.

TABLE 4

PERCENTAGE OF EXTRACTION IN PANELS, IN ENTRIES, AND TOTAL EXTRACTION[1]

Length of Rooms (Feet)	Number of Rooms per Room Entry	Percentage of Extraction Inside Each Panel					Percentage of Total Area Extracted in All Panels					Percentage of Total Area Extracted in Entries Outside Panels	Total Percentage Extracted				
		20-ft. Rooms	25-ft. Rooms	30-ft. Rooms	35-ft. Rooms	40-ft. Rooms	20-ft. Rooms	25-ft. Rooms	30-ft. Rooms	35-ft. Rooms	40-ft. Rooms		20-ft. Rooms	25-ft. Rooms	30-ft. Rooms	35-ft. Rooms	40-ft. Rooms
200	8	51.12	58.87	66.62	74.38	82.13	31.78	36.60	41.42	46.24	51.06	5.32	37.10	41.92	46.74	51.56	56.38
	12	50.46	57.99	65.52	73.05	80.59	35.42	40.71	46.00	51.28	56.57	3.94	39.36	44.65	49.94	55.22	60.51
	16	50.14	57.56	64.99	72.41	79.84	38.65	44.37	50.10	55.82	61.55	2.59	41.24	46.96	52.69	58.41	64.14
	20	49.95	57.31	64.67	72.04	79.40	39.19	44.96	50.73	56.51	62.29	2.51	41.70	47.47	53.24	59.02	64.80
	24	49.82	57.15	64.47	71.79	79.10	39.08	44.83	50.58	56.32	62.05	2.51	41.59	47.34	53.09	58.83	64.56
	28	49.74	57.03	64.32	71.61	78.91	39.43	45.21	50.99	56.77	62.56	2.51	41.94	47.72	53.50	59.28	65.07
250	8	53.25	60.92	68.59	76.26	83.93	33.39	38.20	43.01	47.82	52.63	5.10	38.69	43.30	48.11	52.92	57.73
	12	52.65	60.09	67.52	74.92	82.39	37.27	42.54	47.80	53.04	58.33	3.79	41.06	46.33	51.59	56.83	62.12
	16	52.35	59.67	66.99	74.01	81.62	40.70	46.40	52.09	57.55	63.47	2.50	43.20	48.90	54.59	60.15	65.97
	20	52.18	59.43	66.67	73.93	81.17	41.30	47.03	52.76	58.51	64.24	2.44	43.74	49.47	55.20	60.95	66.68
	24	52.05	59.27	66.47	73.67	80.86	41.19	46.90	52.60	58.30	63.98	2.44	43.63	49.34	55.04	60.74	66.42
	28	51.98	59.15	66.36	73.50	80.67	41.57	47.30	53.07	58.78	64.51	2.44	44.01	49.74	55.51	61.22	66.95
300	8	54.75	62.37	69.98	77.60	85.21	34.62	39.45	44.26	49.08	53.90	5.08	39.70	44.53	49.34	54.16	58.98
	12	54.17	61.53	68.89	76.26	83.62	38.68	43.94	49.19	54.46	59.71	3.79	42.47	47.73	52.98	58.25	63.50
	16	53.88	61.12	68.37	75.61	82.85	42.26	47.94	53.63	59.30	64.98	2.50	44.76	50.44	56.13	61.80	67.48
	20	53.71	60.88	68.06	75.23	82.40	42.87	48.59	54.32	60.04	65.76	2.44	45.31	51.03	56.76	62.48	68.20
	24	53.60	60.73	67.85	74.98	82.10	42.78	48.47	54.15	59.84	65.52	2.44	45.22	50.91	56.59	62.28	67.96
	28	53.52	60.62	67.71	74.80	81.89	43.16	48.89	54.61	60.33	66.04	2.44	45.60	51.33	57.05	62.77	68.48

[1]Room centers 50 feet in all cases.

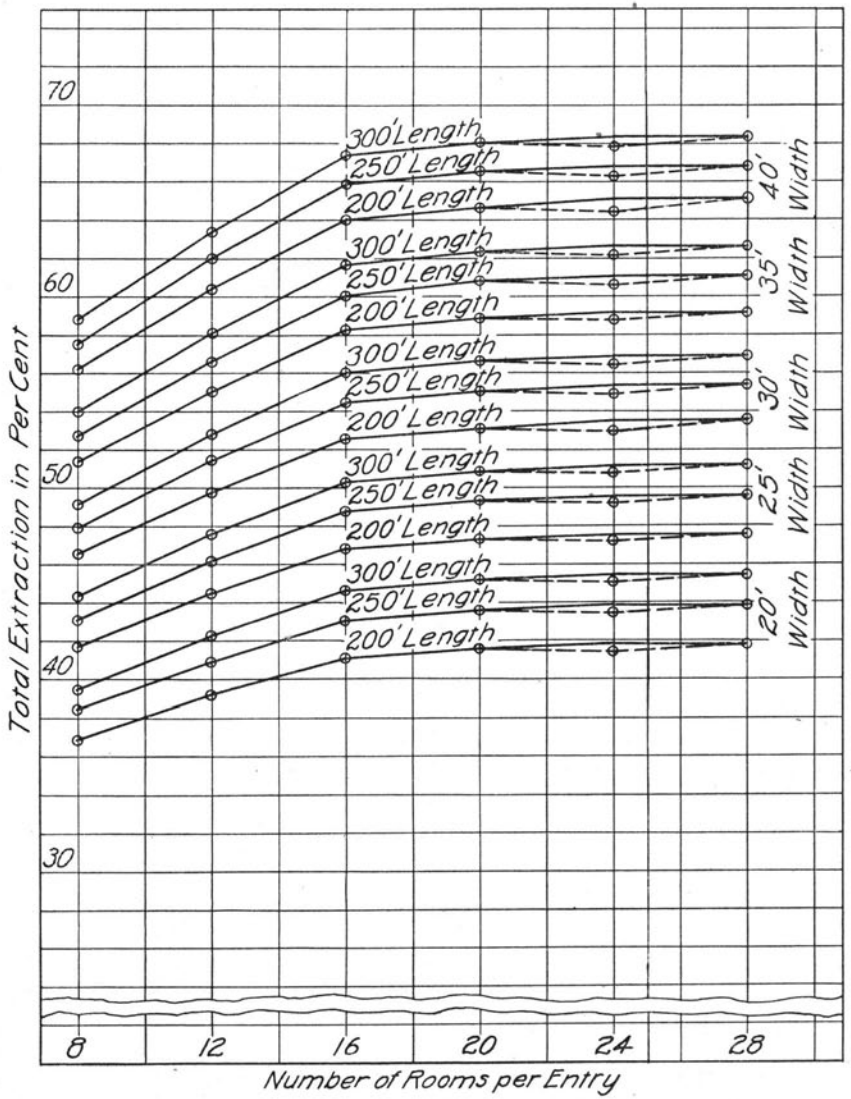

FIG. 6. TOTAL PERCENTAGE OF EXTRACTION

The decrease in length of cross entries with increase of number of rooms per entry ceases at about 16 rooms per entry. If a larger area were considered, the change would be less abrupt than it is.

Table 4 gives the percentages of extraction for all widths of rooms considered. The first group of figures in columns 3, 4, 5, 6, and 7, gives the percentage of extraction inside the panel for each width of room, for each length of room and for each number of rooms per entry. The second group of figures, given in columns 8, 9, 10, 11, and 12, gives the percentage of total area extracted in panels for each width of room, each length of room, and each number of rooms per entry. In each case this percentage is obtained by multiplying the percentage of extraction inside the panel by the percentage of area occupied by panels. The values in column 13 give the percentage of area extracted in entries outside the panels.

The third group of figures, given in columns 14, 15, 16, 17, and 18, gives the total percentage of extraction. This percentage is obtained in each case by adding to the percentage of area extracted in panels the percentage of area extracted in entries outside the panels.

It will be noted that the total percentage of extraction is increased by increasing the length of rooms, the width of the rooms and the number of rooms per entry.

The values for total extraction given in Table 4 are shown graphically by Fig. 6. This set of diagrams shows plainly, in the broken lines plotted from the figures in the table, one of the irregularities resulting from the use of a small area as a basis for calculation: that is, the apparent drop in total percentage of extraction at 24 rooms per entry. The percentage of extraction does not actually drop at this point, however, the apparent drop being due to the consideration of a limited area. Calculations for 25 rooms per entry place the curve at its approximately proper position, and the solid lines show this position.

Table 5 shows the percentage of loss inside the panel and the percentage of total area lost inside the panels, for all conditions considered. Columns 3 to 7 inclusive give the percentages of loss inside the panel for the different conditions; columns 8 to 12 inclusive give the percentage of total area lost inside the panels. These latter figures are obtained by multiplying the percentage of area devoted to panels by the percentage of loss inside the panels, which is obtained by subtracting the percentage of extraction inside the panel from one hundred.

Table 6 gives the percentages of total area left in pillars outside panels; that is, all coal left in the mine except that in room pillars

TABLE 5

PERCENTAGE LOST IN PANELS

Length of Rooms (Feet)	Number of Rooms per Room Entry	Percentage of Loss Inside Panels.					Percentage of Total Area Lost Inside Panels				
		20-ft. Rooms	25-ft. Rooms	30-ft. Rooms	35-ft. Rooms	40-ft. Rooms	20-ft. Rooms	25-ft. Rooms	30-ft. Rooms	35-ft. Rooms	40-ft. Rooms
200	8	48.88	41.13	33.38	25.62	17.87	30.39	25.57	20.75	15.93	11.11
	12	49.54	42.01	34.48	26.95	19.41	34.64	29.49	24.20	18.92	13.63
	16	49.86	42.44	35.01	27.59	20.16	38.44	32.72	26.99	21.27	15.54
	20	50.05	42.69	35.33	27.96	20.60	39.26	33.49	27.72	21.93	16.16
	24	50.18	42.85	35.53	28.21	20.90	39.37	33.62	27.87	22.13	16.40
	28	50.26	42.97	36.17	28.39	21.67	39.85	33.99	28.68	22.51	17.18
250	8	46.75	39.08	31.41	23.74	16.07	29.32	24.51	19.70	14.89	10.08
	12	47.35	39.91	32.48	25.08	17.61	33.52	28.26	23.00	17.76	12.47
	16	47.65	40.33	33.01	25.99	18.38	37.05	31.36	25.67	20.21	14.29
	20	47.82	40.57	33.33	26.07	18.73	37.84	32.11	26.38	20.63	14.82
	24	47.96	40.73	33.53	26.33	19.14	37.94	32.23	26.53	20.83	15.15
	28	48.02	40.85	33.64	26.50	19.33	38.40	32.67	26.90	21.19	15.46
300	8	45.25	37.63	30.02	22.40	14.79	28.62	23.80	18.99	14.17	9.35
	12	45.83	38.47	31.11	23.74	16.38	32.73	27.47	22.22	16.95	11.70
	16	46.12	38.88	31.63	24.39	17.15	36.17	30.49	24.81	19.13	13.45
	20	46.29	39.12	31.94	24.77	17.60	36.94	31.22	25.49	19.77	14.05
	24	46.40	39.27	32.15	25.02	17.90	37.03	31.34	25.66	19.97	14.29
	28	46.48	39.38	32.29	25.20	18.11	37.49	31.76	26.04	20.33	14.61

TABLE 6

PERCENTAGE LOST IN PILLARS OUTSIDE THE PANELS EXCEPT IN ENTRIES

Length of Rooms (Feet)	Number of Rooms per Room Entry	Percentage of Total Area Left in Pillars Outside Panel Except Entry Pillars					
		Main Entry Barriers	Cross Entry Barriers	Total in Entry Barriers	At Ends of Panels	At Sides of Panels	Total
200	8	7.34	18.41	25.75	1.72	2.15	29.62
	12	7.42	12.96	20.38	0.86	2.43	23.67
	16	7.50	7.82	15.32	0.86	2.67	18.85
	20	7.50	6.48	13.98	0.86	2.72	17.56
	24	7.50	6.48	13.98	0.86	2.72	17.56
	28	7.50	6.48	13.98	0.00	2.74	16.72
250	8	7.34	18.63	25.97	1.72	1.61	29.30
	12	7.42	13.12	20.54	0.86	1.82	23.22
	16	7.50	7.92	15.42	0.86	2.00	18.28
	20	7.50	6.56	14.06	0.86	2.04	16.96
	24	7.50	6.56	14.06	0.86	2.04	16.96
	28	7.50	6.56	14.06	0.00	2.06	16.12
300	8	7.34	18.63	25.97	1.72	1.08	28.77
	12	7.42	13.12	20.54	0.86	1.22	22.62
	16	7.50	7.92	15.42	0.86	1.34	17.62
	20	7.50	6.56	14.06	0.86	1.36	16.28
	24	7.50	6.56	14.06	0.86	1.36	16.28
	28	7.50	6.56	14.06	0.00	1.37	15.43

and entry pillars. Column 3 gives the percentage of total area occupied by the main entry barriers; column 4 the percentage of total area occupied by cross entry barriers; and column 5 the percentage of total area in all entry barriers, the sum of the two preceding columns. Column 6 gives the percentage of total area left in pillars at ends of panels, column 7 the percentage of total area left in pillars at sides of panels, and column 8 the percentage of total area left in pillars outside the panels except in entries. Column 8 represents the sum obtained by adding together the proper figures in columns 3, 4, 6, and 7.

TABLE 7

EXTRACTION IN WIDE WORK AND IN NARROW WORK

Length of Rooms (Feet)	Number of Rooms per Room Entry	Percentage of Total Extraction Obtained from Narrow Work					Percentage of Total Extraction Obtained from Wide Work				
		20-ft. Rooms	25-ft. Rooms	30-ft. Rooms	35-ft. Rooms	40-ft. Rooms	20-ft. Rooms	25-ft. Rooms	30-ft. Rooms	35-ft. Rooms	40-ft. Rooms
200	8	24.26	21.47	19.26	17.46	15.96	75.74	78.53	80.74	82.54	84.04
	12	20.55	18.12	16.20	14.65	13.37	79.45	81.88	83.80	85.35	86.63
	16	17.34	15.23	13.57	12.24	11.15	82.66	84.77	86.43	87.76	88.85
	20	17.15	15.06	13.43	12.11	11.03	82.85	84.94	86.57	87.89	88.97
	24	17.19	15.10	13.47	12.15	11.07	82.81	84.90	86.53	87.85	88.93
	28	17.17	15.09	13.46	12.15	11.07	82.83	84.91	86.54	87.85	88.93
250	8	20.78	18.57	16.71	15.19	13.93	79.22	81.43	83.29	84.81	86.07
	12	17.32	15.35	13.78	12.51	11.45	82.68	84.65	86.22	87.49	88.55
	16	14.21	12.56	11.19	10.21	9.31	85.79	87.44	88.81	89.79	90.69
	20	14.06	12.43	11.14	10.09	9.22	85.94	87.57	88.86	89.91	90.78
	24	14.10	12.47	11.17	10.13	9.26	85.90	87.53	88.83	89.87	90.74
	28	14.07	12.45	11.15	10.11	9.25	85.93	87.55	88.85	89.89	90.75
300	8	20.25	18.06	16.30	14.85	13.63	79.75	81.94	83.70	85.15	86.37
	12	16.74	14.90	13.42	12.21	11.20	83.26	85.10	86.58	87.79	88.80
	16	13.72	12.17	10.94	9.94	9.10	86.28	87.83	89.06	90.06	90.90
	20	13.57	12.05	10.84	9.84	9.02	86.43	87.95	89.16	90.16	90.98
	24	13.60	12.08	10.87	9.87	9.05	86.40	87.92	89.13	90.13	90.95
	28	13.57	12.06	10.85	9.86	9.04	86.43	87.94	89.15	90.14	90.96

Table 7 gives a comparison between the total extraction made in narrow work and that made in wide work. Columns 3 to 7, inclusive, give the percentage of total extraction obtained from narrow work; that is, from entries and entry cross-cuts for all conditions considered. In each case the total extraction, whatever the actual figure, is considered 100 per cent. Columns 8 to 12, inclusive, give the percentage of total extraction obtained from wide work; that is, from rooms, room necks, and room cross-cuts. When these values are considered, it should be remembered that the limit between wide work and narrow work has been set arbitrarily. It is considered for

the purpose of these calculations that all workings less than 18 feet in width are narrow work and all workings 18 feet or more in width are wide work. It is to be noted that the percentage of the total extraction obtained from narrow work decreases as the length of rooms increases, as the number of rooms per entry increases, and as the width of rooms in relation to width of room pillars increases.

As narrow work is more expensive than wide work, efforts will be made to reduce it to the minimum in places where the conditions of roof and floor permit. This reduction can sometimes be accomplished by increasing the width of entries and entry cross-cuts. Where this increase is impossible, the only means of reducing the amount of narrow work is by decreasing the length of entries, assuming that room cross-cuts and room necks are wide work. This assumption, however, is not always true. The work of J. C. Quade (see Appendix I) illustrates the reduction of narrow work by increase of the width of room cross-cuts.

Summaries of the percentages won and lost in different portions of the workings are given in Figs. 7, 8, and 9, which illustrate the results with rooms 25 feet wide, and 200, 250, and 300 feet long respectively. In each case the total height of the diagram represents 100 per cent of area. The height from the bottom border to the first line represents the percentage of total area extracted inside the panels; the height from the first line to the second represents the percentage extracted in entries outside the panels; the height from the second line to the third represents the percentage lost in entries outside the panels; the height from the third line to the fourth represents the percentage lost in pillars outside the panels; and the height from the fourth line to the top of the figure represents the percentage lost inside the panels. As these diagrams are based only upon results with 25-foot rooms on 50-foot centers, no changes of percentage of extraction are involved that are dependent upon change of room width.

These diagrams illustrate the final disposal of the coal in the area considered; they show the amounts won and lost, and the general distribution of extraction and losses. The coal extracted comes from panels and from entries outside the panels, the larger part coming from the panels. As the number of rooms per entry increases, the amount of coal taken from the panels increases, but in the example considered it remains fairly constant after the number of rooms per entry reaches about twenty.

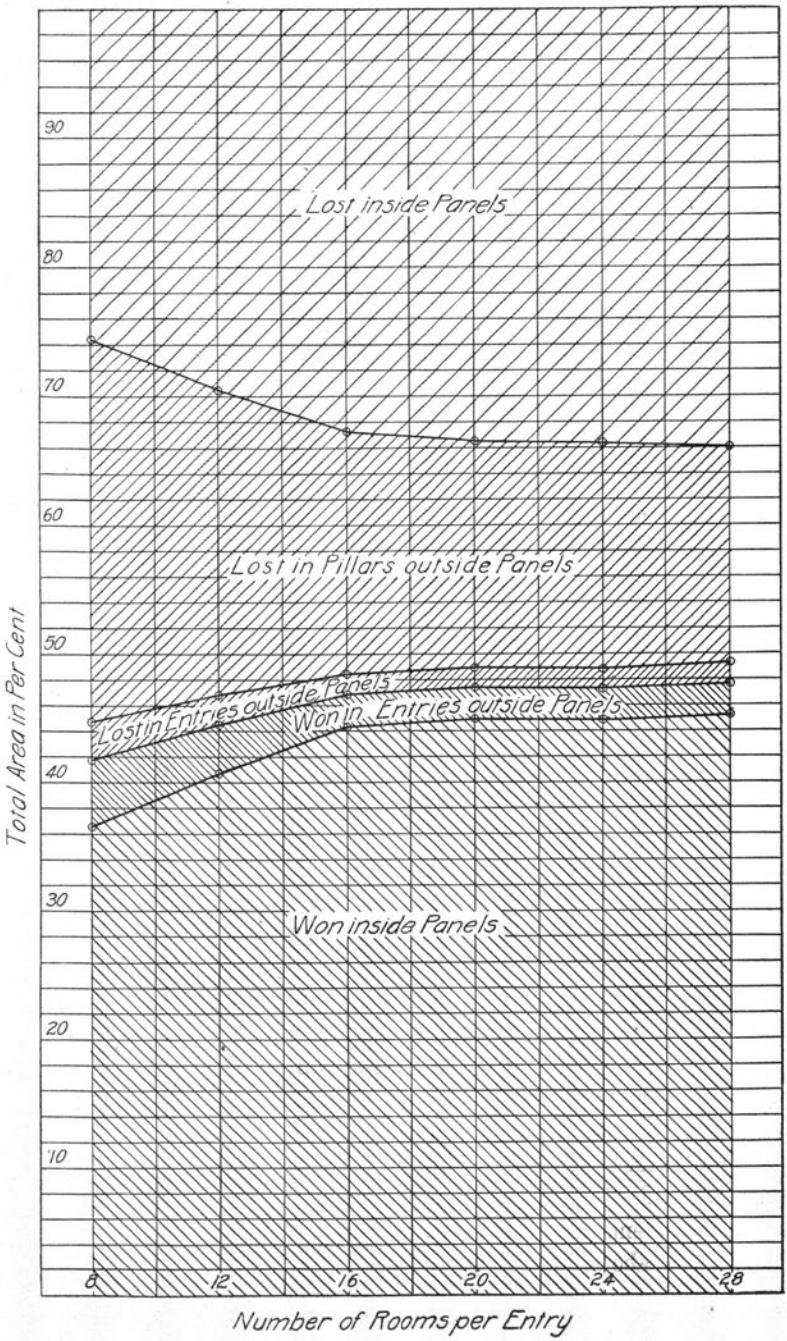

FIG. 7. DISTRIBUTION OF EXTRACTION AND LOSS FOR ROOMS 200 FEET LONG, 25 FEET WIDE, ON 50-FOOT CENTERS

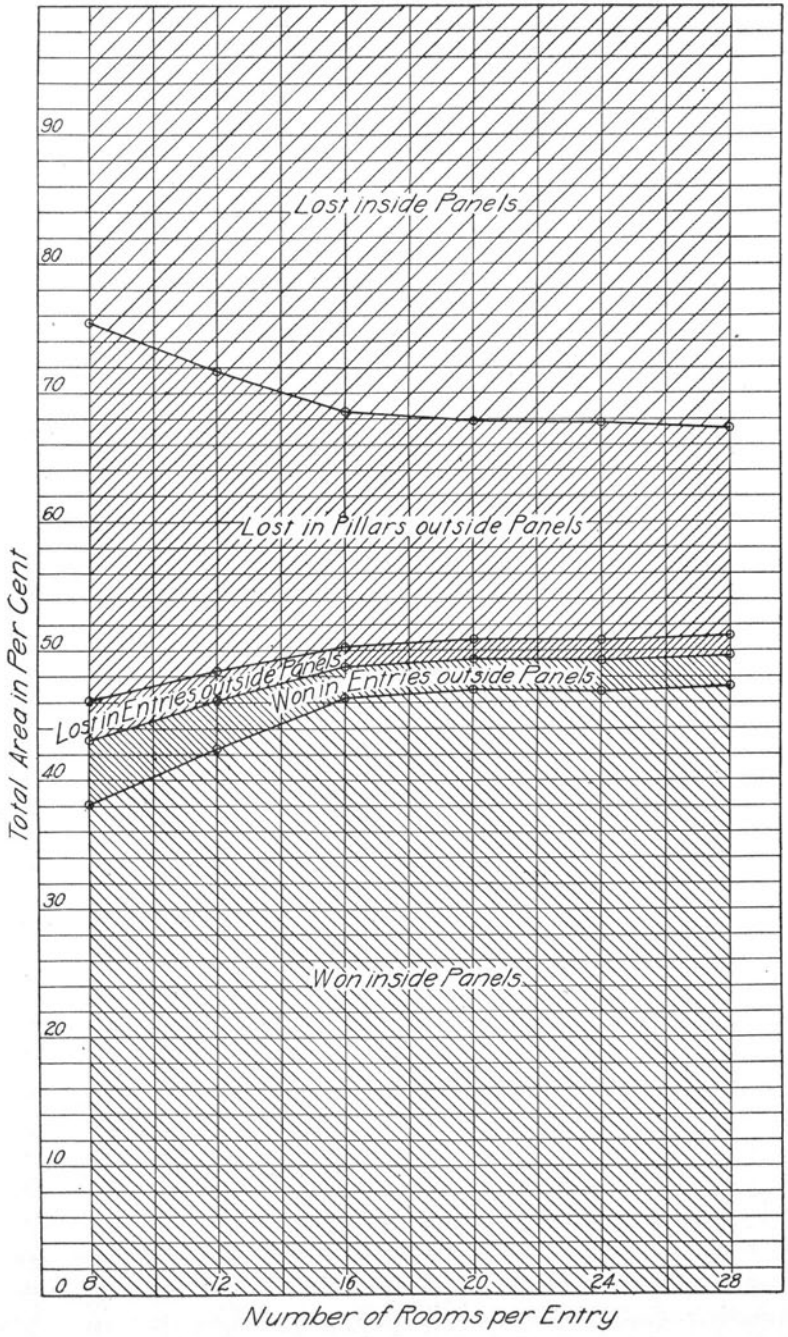

FIG. 8. DISTRIBUTION OF EXTRACTION AND LOSS FOR ROOMS 250 FEET LONG, 25 FEET WIDE, ON 50-FOOT CENTERS

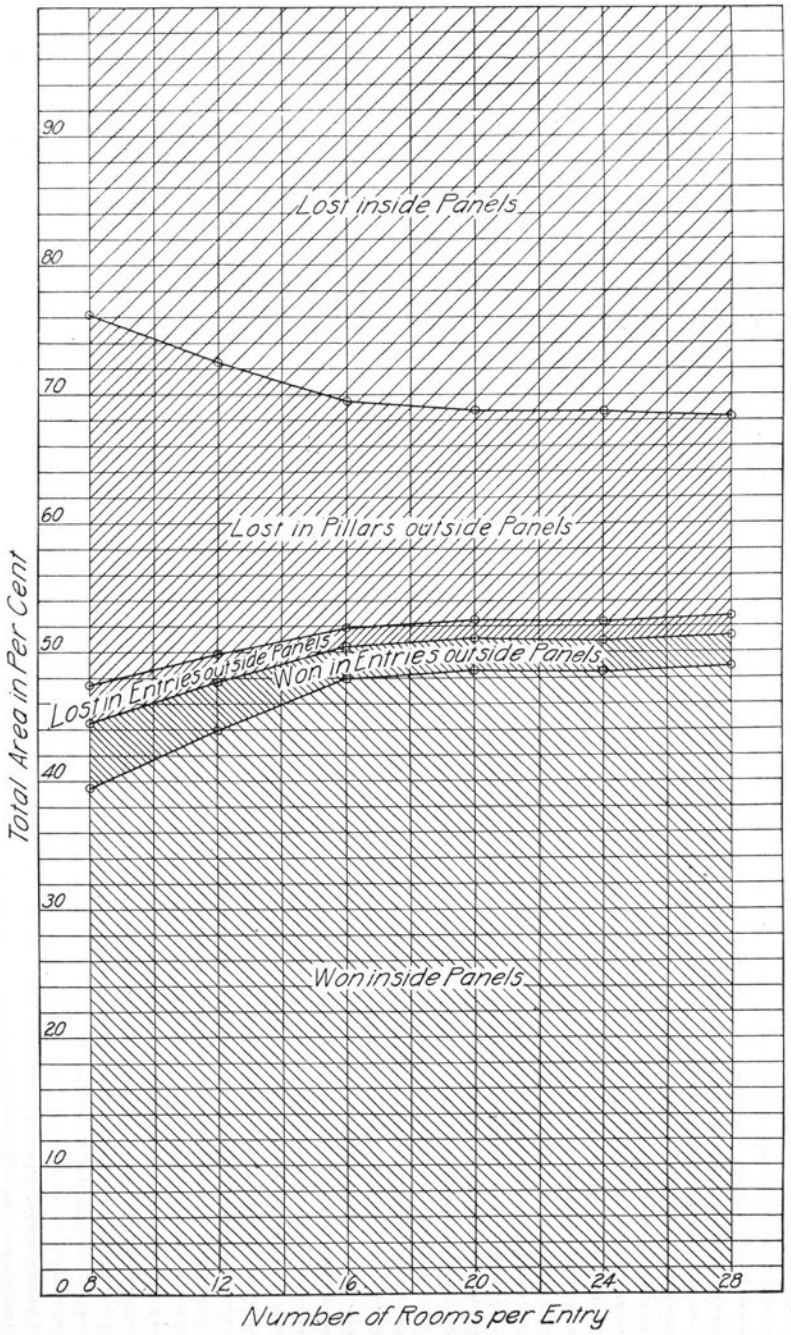

FIG. 9. DISTRIBUTION OF EXTRACTION AND LOSS FOR ROOMS 300 FEET LONG, 25 FEET WIDE, ON 50-FOOT CENTERS

With the increase of number of rooms per entry there is a slight decrease in the percentage extracted from entries outside the panels and also a slight decrease in the coal lost in entries outside the panels, both decreases being due to reduction of area occupied by entries. It is shown plainly that the amount of coal lost and won in entries is not large in any case.

One thing clearly indicated is that the increased extraction which accompanies increase of number of rooms per entry is due largely to a decrease in loss in pillars outside the panels; that is, to decrease of space occupied by barrier pillars. It is also shown that this decrease is much less rapid after rather than before approximately 16 rooms per entry have been reached and that beyond 20 rooms per entry there is very little change.

The fact that the lines become nearly horizontal after 16 to 20 rooms per entry have been reached shows that no material increase of percentage of extraction can be made by further increasing the number of rooms per entry. Comparison of the three diagrams shows also that very slight additional extraction can be accomplished by lengthening rooms. It follows, therefore, that the only two ways of increasing extraction are by increase of ratio of room width to pillar width and by extraction of pillar coal. These two methods may be said to reduce the loss in room pillars, but by entirely different means. It has been proved by experience that attempts to increase room width at the expense of pillar width are dangerous, and it is believed that the greatest ratio of room width used in the preceding discussion,—namely, four to one, considerably exceeds any limit which would ordinarily be safe for operation. It therefore follows that increase of extraction can be attained only by adopting some method for removing pillar coal after the rooms have been driven.

26. *Other Methods of Computation.*—It is recognized that the inclusion of the main entry and its barrier pillars in the tract considered gives percentages of extraction that must be changed somewhat if applied to larger areas, because the ratio of barrier pillar to total area is greater than would be the case in a larger area. This error could be avoided to some extent by choosing the part of the mine to be examined so that the main entry would not be included; thus the computed extraction would be a little too high.

Irregularities due to the limiting of the area considered could be

avoided by a method of computation suggested by C. W. Hippard. Instead of a unit area of 160 acres, the area served by a pair of room entries with half of the adjoining cross entry and barriers and half of the surrounding fire pillars is considered. Such an area, which may be called a unit panel, is shown enclosed by dotted lines in Fig. 10.

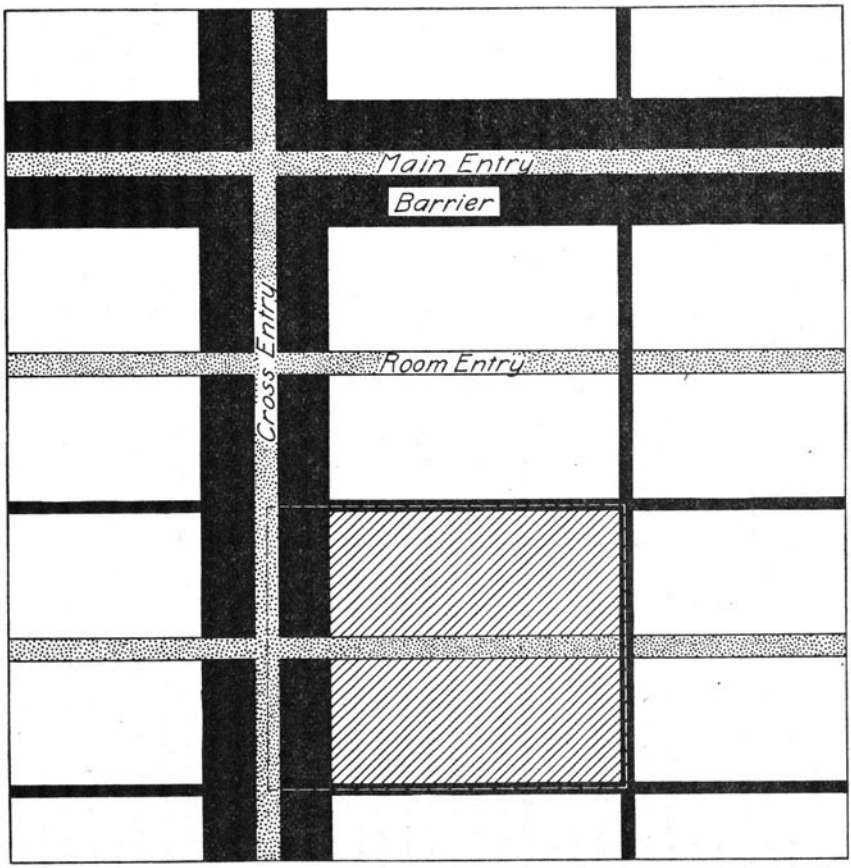

FIG. 10. UNIT PANEL

A single panel with its proper share of cross entry, barriers, and fire pillars is considered a true sample of the mine. The area of the tract considered is not constant, but changes with length of rooms, width of rooms, and number of rooms per panel. As the proportion of the main entry and barriers properly chargeable to this unit area changes with the size of the tract considered, it is best not to include

main entry and barriers in the calculation. Calculated percentages of extraction are then a little too high.

The following computation by this method illustrates the procedure. The dimensions considered are those given on page 18.

Area of panel except room entry, (p. 21), 287,500 square feet
Percentage of extraction in room-and-pillar area, (p. 21), 59.91 per cent
Area excavated in panel except room entry,
$0.5991 \times 287{,}500 =$ . . . . . 172,241 square feet
Area occupied by room entry,
$44 \times 675 = 29{,}700$ square feet
Percentage of extraction in room entry,
(p. 21), 62.12 per cent
Area excavated in room entry,
$0.6212 \times 29{,}700 =$ . . . . . 18,450 square feet
Area occupied by cross entry,
$\frac{1}{2} \times 49 \times 564 = 13{,}818$ square feet
Percentage of extraction in cross entry,
(p. 22), 57.48 per cent
Area excavated in cross entry,
$0.5748 \times 13{,}818 =$ . . . . . 7,943 square feet

Total area excavated . . . . 198,634 square feet

Area of tract considered,
$564 \times 712 = 401{,}568$ square feet
Percentage of extraction

$$\frac{198{,}634 \times 100}{401{,}568} = 49.47 \text{ per cent}$$

This result is 3.14 per cent greater than the extraction calculated by the method described on pages 18 to 24, the difference being due to the exclusion of the main entry and its barriers in the unit panel method. Calculations by the latter method with other numbers of rooms per entry give the following results:

	Extraction
16 rooms per entry	50.98 per cent
20 rooms per entry	51.96 per cent
24 rooms per entry	52.64 per cent
28 rooms per entry	53.14 per cent

The percentages thus obtained agree closely with those previously calculated.

APPENDIX I

Cost of Production and the Percentage of Extraction in Fulton County

Work of J. C. Quade

An investigation of the percentage of extraction in the Fulton County field has been made by J. C. Quade, Chief Engineer of the Big Creek Coal Company and of the Saline County Coal Company. The results of this investigation are in part reproduced in the following pages through the courtesy of Mr. Quade who has reviewed the summary.

These computations were made chiefly to find means of reducing the cost of production, the computation of extraction being incidental but necessary to the computation of cost. The results show that the highest percentage of extraction accompanied the lowest cost of production per thousand tons.

In making computations of cost no attention was paid to the total cost of production, but only to the items which would be directly modified by changes of dimensions of workings. The values of these were determined in part by the prices fixed in the agreement with the United Mine Workers and in part by practice in the Fulton County field.

The items considered in the computation are:

Yardage paid for narrow work.
Room turning.
Switch laying.
Wood track.
Props.

These items are intended to cover labor and materials not directly employed in the extraction of coal. The materials considered are those from which little if any salvage is expected. Such large items of expense as mining, haulage, ventilation, drainage, interest on capital and amortization are omitted because they are little affected by the changes contemplated. The expense of maintaining the various items considered is small in comparison with the total cost of production,

but the calculation includes those items which are most immediately and completely affected by changes in the dimensions of workings.

The method of computation was determined by the fact that the company had an area of 160 acres in Fulton County which was soon to be developed. The tract was in the form of a square with public roads on two sides, coal owned by the company on the third side, and coal not owned by the company on the fourth side. It was therefore necessary to leave pillars along three borders but not along the fourth. This tract was laid out with two main entries, and with six cross entries where 210-foot rooms are considered and seven cross entries where 180-foot rooms are considered as shown in Fig. 11. The form of the field and the necessity of leaving boundary pillars in-

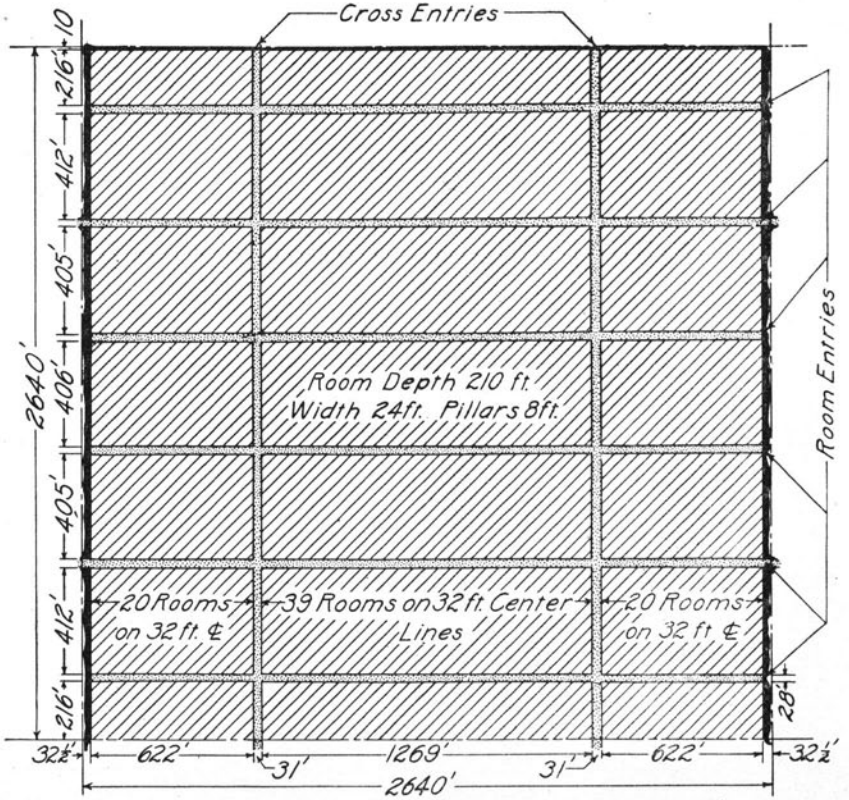

FIG. 11. MAP OF 160 ACRES FOR J. C. QUADE'S COMPUTATION

fluenced both the lengths of entries and the number of rooms. The coal lying east and west of this tract was developed later; hence two pairs of room entries were extended through the boundary pillars on each side to become the cross entries of the newer developments.

Only two lengths of rooms were considered: 180 feet because that length was then being used by the company, and 210 feet because experience had shown this to be the maximum length for a room which could commonly be kept open for the time required to complete extraction without considerable expense for retimbering.

An analysis of the fixed costs in the district in which the mine is located showed that the yardage paid for narrow work in room cross-cuts was responsible for a considerable share of these costs. This yardage could be eliminated by driving room cross-cuts wider than the limit for which yardage is paid, or could be reduced by decreasing the length of the room cross-cuts by making pillars narrower. The calculations involve both methods.

The following items of cost are based upon conditions in the Fulton County field at the time when the calculations were made.

Mining rates fixed by agreement between the United Mine Workers and Operators.

	Per Yard
Pick rate, 8-foot entries	$1.82
12-foot entries	1.24
16-foot entries	0.00
Room turning	4.55
Machine rate, 8-foot entries	1.46
12-foot entries	1.00
16-foot entries	0.00
Room turning	3.64

Items fixed by the experience of the company in the Fulton County Field.

Switch laying and ties	$4.00 per room
Props	0.005 per square foot
Each prop costing $0.06 and supporting an average of 12 square feet of roof.	
Wood rails, 1.3 times the length of the room at	$22.00 per 1000 board feet
	6.25 for 180-foot room
	7.45 for 210-foot room
Track laying and ties	0.10 per foot
Brushing and timbering entries, approximately $3.00 per foot for 25 per cent of the length of the entry	0.75 per foot

Some of the figures given would not be applicable at present, but the method used can be applied by changing the expense of various items to correspond with changes in conditions.

In computing the production to be expected from different dimensions of workings, it is assumed that 25 cubic feet of coal in place are equivalent to one ton, and that 5.70 square feet of area are equivalent to a production of one ton if proper allowances are made for the thickness of the coal, which averages 4 feet, 10 inches, and for the waste which always accompanies mining. It is assumed that rooms from adjoining cross entries are driven through until they meet and that five cross-cuts are driven in the length of the two 180-foot rooms and six in the length of the two 210-foot rooms. This arrangement accounts for the average number of cross-cuts being 2½ for a 180-foot room.

The following tables give the essential data on which the calculations are based. Table 8 gives the number of rooms in 160 acres, for each room width and for each pillar width, for rooms 180 feet long and 210 feet long. The total number of rooms varies less regu-

TABLE 8

NUMBER OF ROOMS IN 160 ACRES

Room Width (Feet)	Room Length and Centers	Pillar Width								
		6	7	8	9	10	11	12	16	20
20	180	**1330**	**1298**	**1232**	**1204**	**1162**	**1120**	**1106**	**980**	**882**
	Centers	26	27	28	29	30	31	32	36	40
	210	**1140**	**1104**	**1056**	**1032**	**996**	**960**	**948**	**840**	**756**
21	180	**1298**	**1232**	**1204**	**1162**	**1120**	**1106**	**1050**	**952**	**840**
	Centers	27	28	29	30	31	32	33	37	41
	210	**1104**	**1056**	**1032**	**996**	**960**	**948**	**900**	**816**	**720**
22	180	**1232**	**1204**	**1162**	**1120**	**1106**	**1050**	**1036**	**938**	**840**
	Centers	28	29	30	31	32	33	34	38	42
	210	**1056**	**1032**	**996**	**960**	**948**	**900**	**888**	**804**	**720**
23	180	**1204**	**1162**	**1120**	**1106**	**1050**	**1036**	**994**	**896**	**826**
	Centers	29	30	31	32	33	34	35	39	43
	210	**1032**	**996**	**960**	**948**	**900**	**888**	**852**	**768**	**708**
24	180	**1162**	**1120**	**1106**	**1050**	**1036**	**994**	**980**	**882**	**784**
	Centers	30	31	32	33	34	35	36	40	44
	210	**996**	**960**	**948**	**900**	**888**	**852**	**840**	**756**	**672**
25	180	**1120**	**1106**	**1050**	**1036**	**994**	**980**	**952**	**840**	**784**
	Centers	31	32	33	34	35	36	37	41	45
	210	**960**	**948**	**900**	**888**	**852**	**840**	**816**	**720**	**672**
26	180	**1106**	**1050**	**1036**	**994**	**980**	**952**	**938**	**840**	**770**
	Centers	32	33	34	35	36	37	38	42	46
	210	**948**	**900**	**888**	**852**	**840**	**816**	**804**	**720**	**660**

larly than the dimensions, because no fractional rooms were considered, but only such arrangements of whole rooms as would most nearly completely cover the 160-acre tract.

TABLE 9

AREA OF ROOMS[1] AND TONS OF COAL PER ROOM[2]

Width of Rooms (Feet)	Length 180 Feet		Length 210 Feet	
	Area (Square Feet)	Tons	Area (Square Feet)	Tons
20	3382	593.33	3982	698.60
21	3546.5	622.16	4176.5	732.32
22	3711	651.05	4371	766.84
23	3875.5	679.91	4565.5	800.96
24	4040	708.77	4760	835.08
25	4204.5	737.63	4954.5	869.20
26	4369	766.50	5149	903.33

[1]Not including cross-cuts.

[2]5.70 square feet of 4-foot, 10-inch coal per ton, allowing for waste.

TABLE 10

AREA OF ROOM CROSS-CUTS (PER CROSS-CUT), TONS OF COAL PRODUCED AND YARDAGE COST[1]

Width of Pillar (Feet)	8-ft. Cross-Cut			12-ft. Cross-Cut			16-ft. Cross-Cut		
	Area (Square Feet)	Tons of Coal at 5.70 Square Feet per Ton	Yardage Cost at 60⅔ cents per Foot	Area (Square Feet)	Tons of Coal at 5.70 Square Feet per Ton	Yardage Cost at 41⅓ cents per Foot	Area (Square Feet)	Tons of Coal at 5.70 Square Feet per Ton	Yardage Cost 0.00
6	48	8.41	$3.64	72	12.62	$2.48	96	16.84	.....
7	56	9.83	4.25	84	14.74	2.89	112	19.65	.....
8	64	11.23	4.85	96	16.84	3.31	128	22.46	.....
9	72	12.63	5.46	108	18.94	3.72	144	25.26	.....
10	80	14.03	6.07	120	21.05	4.14	160	28.07	.....
11	88	15.44	6.67	132	23.16	4.55	176	30.88	.....
12	96	16.84	7.28	144	25.66	4.96	192	33.68	.....
16	128	22.46	9.71	192	33.69	6.61	256	44.91	.....
20	160	28.07	12.13	240	42.10	8.27	320	56.14	.....

[1]Yardage for narrow work, pick rate:

8 feet wide $1.82 = 60⅔ cents per foot.
12 feet wide 1.24 = 41⅓ cents per foot.
16 feet wide 0.00 = 00 cents per foot.

Table 9 gives the areas of rooms, not including cross-cuts, and the tons of coal per room calculated on the basis of 5.70 square feet per ton.

Table 10 gives for each cross-cut the area, the tons of coal produced, and the yardage cost. The number of tons produced is calculated from the area on the basis of 5.70 square feet per ton. The yardage cost is calculated from the prices fixed in the agreement with the United Mine Workers. Only the rate for pick mining was considered as machines were not used much in the district when the data were compiled. The ratio between yardage cost for 8-foot and 12-foot cross-cuts is the same for pick work as for machine work; therefore if the rates for machine work were substituted in place of those for pick work in the calculations, the results would show a decrease in the total expense, but the percentage of the total expense for narrow work saved by the reduction in the amount of this work would remain the same. Three widths of cross-cuts were considered: 8 feet, which is assumed to be the minimum practical width (this is the minimum width for which a yardage price is fixed in the agreement with the United Mine Workers); 12 feet, which is considered an average; and 16 feet, which, according to the agreement, is wide work and does not require extra compensation.

TABLE 11
TOTAL CROSS-CUT YARDAGE COST PER ROOM

Width of Pillar (Feet)	8-ft. Cross-Cuts		12-ft. Cross-Cuts	
	180-ft. Room 2½ Cross-Cuts	210-ft. Room 3 Cross-Cuts	180-ft. Room 2½ Cross-Cuts	210-ft. Room 3 Cross-Cuts
6	$ 9.10	10.92	6.20	7.44
7	10.63	12.75	7.23	8.67
8	12.13	14.55	8.28	9.93
9	13.65	16.38	9.30	11.16
10	15.18	18.21	10.35	12.42
11	16.68	20.01	11.38	13.65
12	18.20	21.84	12.40	14.88
16	24.28	29.12	16.53	19.84
20	30.33	36.39	20.67	24.80

Table 11 gives the total cross-cut yardage cost per room, obtained by multiplying the cost per cross-cut as given in Table 3 by the proper number of cross-cuts.

TABLE 12

TONS OF COAL IN CROSS-CUTS PER ROOM

Width of Pillar (Feet)	180-ft. Room 2½ Cross-Cuts		210-ft. Room 3 Cross-Cuts	
	8-ft. Cross-Cut	16-ft. Cross-Cut	8-ft. Cross-Cut	16-ft. Cross-Cut
6	21.02	42.04	25.23	50.46
7	24.58	49.16	29.49	58.98
8	28.07	56.14	33.69	67.38
9	31.57	63.14	37.89	75.78
10	35.08	70.16	42.09	84.18
11	38.60	77.20	46.32	92.64
12	42.09	84.18	50.52	101.04
16	56.15	112.30	67.38	134.76
20	70.17	140.34	84.21	168.42

TABLE 13

COST OF PROPS FOR ROOM AND CROSS-CUTS AT ONE-HALF CENT PER SQUARE FOOT, 180-FOOT ROOMS

Width of Room (Feet)	Prop Cost for Room	Width of Pillar								
		6	7	8	9	10	11	12	16	20
		Prop Cost for Cross-Cuts per Room								
		$0.90	$1.05	$1.20	$1.35	$1.50	$1.65	$1.80	$2.40	$3.00
		Prop Cost for Room and Cross-Cuts								
20	$16.91	$17.81	$17.96	$18.11	$18.26	$18.41	$18.56	$18.71	$19.31	$19.91
21	17.73	18.63	18.78	18.93	19.08	19.23	19.38	19.53	20.13	20.73
22	18.56	19.46	19.61	19.76	19.91	20.06	20.21	20.36	20.96	21.56
23	19.38	20.28	20.43	20.58	20.73	20.88	21.03	21.18	21.78	22.38
24	20.20	21.10	21.25	21.40	21.55	21.70	21.85	22.00	22.60	23.20
25	21.02	21.92	22.07	22.22	22.37	22.52	22.67	22.82	23.42	24.02
26	21.85	22.75	22.90	23.05	23.20	23.35	23.50	23.65	24.25	25.85

Table 12 gives the amount of cross-cut coal in tons per room, obtained by dividing the areas of cross-cuts by 5.70, the number of square feet of area equivalent to a production of one ton, and multiplying by the proper number of cross-cuts per room.

TABLE 14

COST OF PROPS FOR ROOM AND CROSS-CUTS AT ONE-HALF CENT PER SQUARE FOOT, 210-FOOT ROOMS

Width of Room (Feet)	Prop Cost for Room	Width of Pillar								
		6	7	8	9	10	11	12	16	2
		Prop Cost for Cross-Cuts per Room								
		$1.08	$1.26	$1.44	$1.62	$1.80	$1.98	$2.16	$2.88	$3.60
		Prop Cost for Room and Cross-Cuts								
20	$19.91	$20.99	$21.17	$21.35	$21.53	$21.71	$21.89	$22.07	$22.79	$23.51
21	20.88	21.96	22.14	22.32	22.50	22.68	22.86	23.04	23.76	24.48
22	21.86	22.94	23.12	23.30	23.48	23.66	23.84	24.02	24.74	25.46
23	22.83	23.91	24.09	24.27	24.45	24.63	24.81	24.99	25.71	26.43
24	23.80	24.88	25.06	25.24	25.42	25.60	25.78	25.96	26.68	27.40
25	24.77	25.85	26.03	26.21	26.39	26.57	26.75	26.93	27.65	28.37
26	25.75	26.83	27.01	27.19	27.37	27.55	27.73	27.91	28.63	29.35

Tables 13 and 14 give the cost of props for a room and its cross-cuts for each width of room from 20 to 26 feet and for each width of pillar from 6 feet to 20 feet. The cost in cents is obtained by dividing the cost per prop, taken as six cents, by the area supported by one prop, 12 square feet, these being figures based upon the experience of the company.

$$\frac{\text{Cost per prop}}{\text{Square feet of area supported}} = \frac{6}{12} = \frac{1}{2} \text{ cent per square foot, or for 1 room}$$

$$\frac{\text{Number of square feet in room}}{2} = \text{cost in cents}$$

In each table the cost of props per room is given at the left, the cost of props for cross-cuts is given at the top, and the cost of props for the rooms and cross-cuts together is given in the body of the table.

These tables of prop costs are computed on the assumption that all cross-cuts are 12 feet wide. In the comparison of total costs, this assumption introduces a small error because this comparison is between 8-foot and 16-foot cross-cuts. To obtain correct values it would be necessary to make allowance for the error thus introduced by

decreasing the prop cost with 8-foot cross-cuts and increasing it with 16-foot cross-cuts. The difference between these two costs would accordingly be decreased, this difference being the saving effected by the use of 16-foot cross-cuts. In rooms of 180 feet long with 6-foot pillars, the error introduced by the use of this average figure amounts to 94 cents per thousand tons. In rooms 210 feet long with 20-foot pillars, the error is $2.09 per thousand tons. These errors are the extremes, and the errors when other dimensions of rooms and pillars are used lie between these two. Since the pillar width selected as the best was small,—viz., 8 feet, the effect of the assumption of 12-foot cross-cuts was small.

The specimen computations given show the methods employed. All essential data are contained in the preceding tables and the calculations involve only the arrangement of these data in such form as clearly to represent the facts and permit comparisons between percentages of extraction and costs of production for different dimensions of rooms.

SPECIMEN COMPUTATIONS

Coal Produced

Rooms and Cross-Cuts

Room width	20 feet
Room length	210 feet
Pillar width	6 feet
Total number of rooms in 160 acres	1140
Room coal	698.60 tons
Coal from 8-foot cross-cuts	25.23 tons
Total coal from room and 8-foot cross-cuts	723.83 tons
Coal from additional 8-feet of cross-cuts	25.23 tons
Total coal per room and 16-foot cross-cuts	749.06 tons

Coal from 160 Acres

	Tons
Total room coal = 698.60 × 1140 =	796,404
Total coal from 8-foot cross-cuts = 25.23 × 1140 =	28,762
Coal from main entry and cross-cuts	16,716
Coal from cross entries and cross-cuts	47,836
Total	889,718
Additional coal from 16-foot cross-cuts	28,762
Grand total	918,480

Cost and Saving

Fixed Room Charges per Room

Room turning	$ 4.55
Switch-laying and ties	4.00
Wood rails	7.45
	$16.00
Props per room and 8-foot cross-cut	21.00
	$37.00
Room cross-cut yardage	10.92
Total for room and cross-cuts	$47.92

Total Fixed Room Charges per 160 Acres

Room turning; switch laying and ties; wood rails, props = $37.00 × 1140 =	$42,180.00
Room cross-cut yardage 10.92 × 1140 =	12,448.80
Total fixed room charges	$54,628.80

Saving by making cross-cuts 16 feet wide . . . . . $12,448.80 = 22.79 per cent fixed room charges with 8-foot cross-cuts

Total Cost for Items Considered

Total fixed room charges	$ 54,628.80
Main entry and cross-cuts, 11,910 feet narrow work at $0.61 per foot	7,265.10
Cross entries and cross-cuts, 34,080 feet narrow work at $0.61 per foot	20,788.80
Track laying	4,176.00
Brushing and timbering	31,320.00
Total cost for 160 acres	$118,178.70
Total cost for 160 acres with 16-foot room cross-cuts, 118,178.70 − 12,448.80 =	$105,729.90

Cost per 1,000 tons with 8-foot room cross-cuts $\frac{118,178.70}{889.718}$ =	132.83
Cost per 1000 tons with 16-foot room cross-cuts $\frac{105,729.90}{918.480}$ =	115.11
Saving per 1000 tons with 16-foot room cross-cuts*	17.72

*The cost per 1000 tons mined is less by one method than by the other, but the quantity of coal considered is greater in the case of 16-foot room cross-cuts by the 28,762 tons gained in the additional 8 feet of cross-cut width.

The accompanying sets of diagrams, Figs. 12 and 13, show the most important points in connection with the percentage of extraction and the cost of production, so far as the latter is determined by the limited elements considered, for all room widths from 20 to 26 feet and for pillar widths of 6, 9, 12, 16, and 20 feet with 210-foot rooms and for 6-foot pillar widths with 180-foot rooms.

Three diagrams in each set are concerned with quantity of production. Diagram *A* gives the number of rooms in 160 acres; diagram *B*, the amount of coal produced per room and cross-cut; and diagram *C* the total amount of coal produced. This total production includes, not only coal taken from rooms and their cross-cuts, but also coal taken from entries and entry cross-cuts.

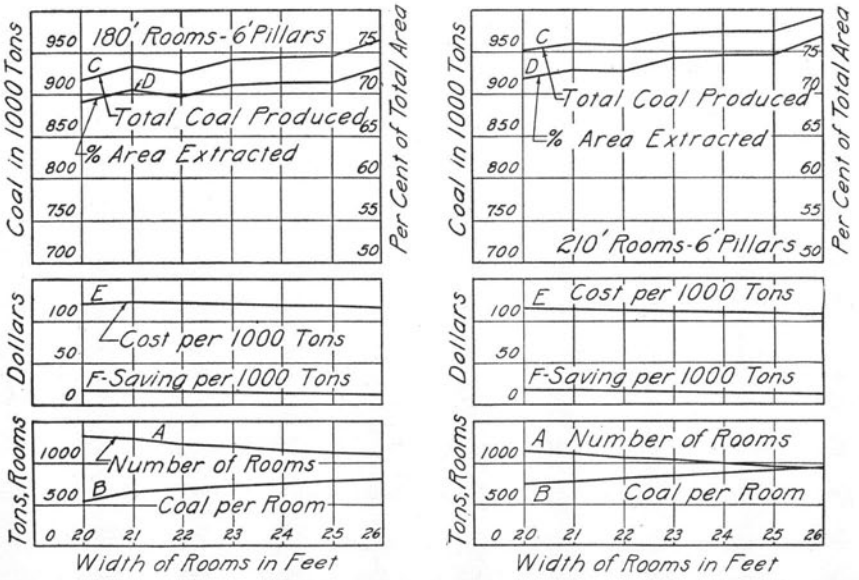

FIG. 12. NUMBER OF ROOMS PER ENTRY, COAL PER ROOM, TOTAL COAL FROM 160 ACRES, PERCENTAGE OF AREA EXCAVATED, COST PER 1000 TONS, SAVING PER 1000 TONS

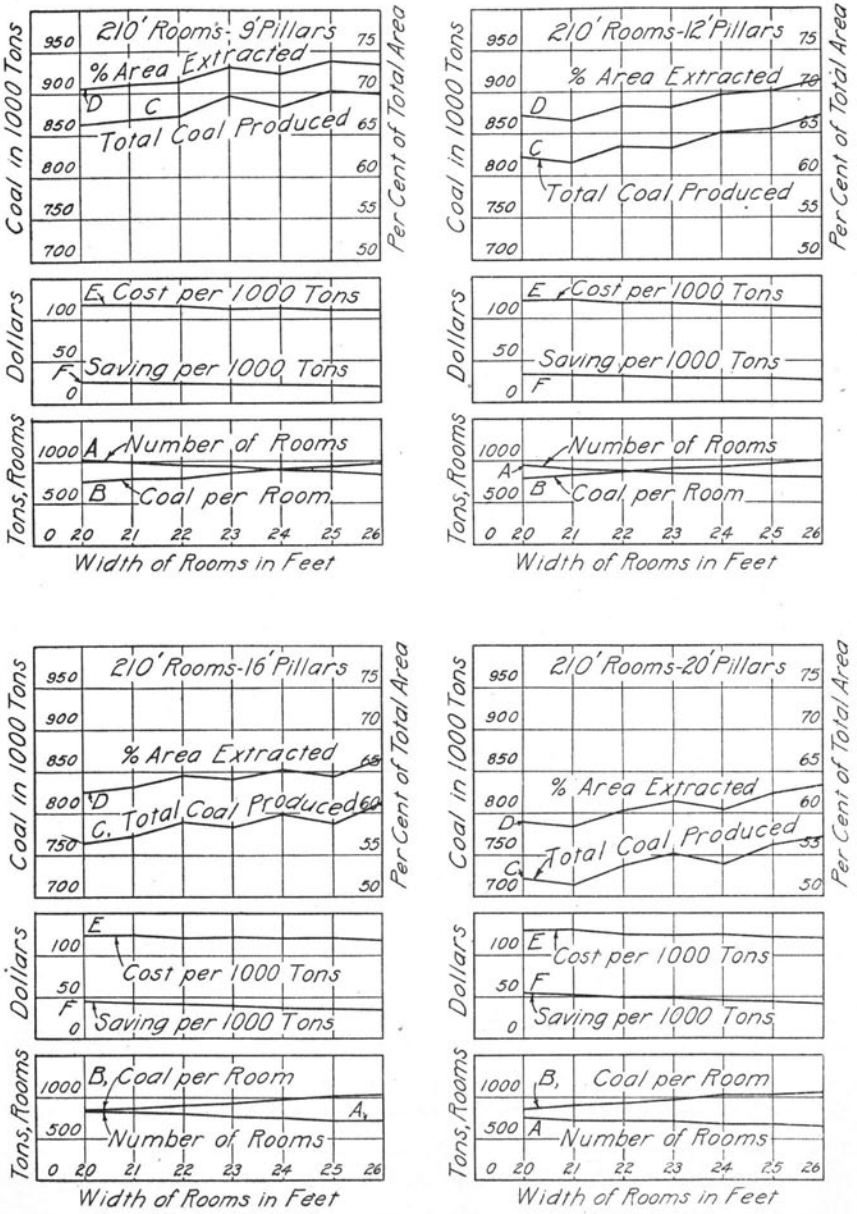

FIG. 13. NUMBER OF ROOMS PER ENTRY, COAL PER ROOM, TOTAL COAL FROM 160 ACRES, PERCENTAGE OF AREA EXCAVATED, COST PER 1000 TONS, SAVING PER 1000 TONS

Diagram *D* shows the percentage of extraction, based on the area excavated instead of on the number of tons produced as calculated by Mr. Quade, in order that this portion of the discussion may be brought into direct comparison with the preceding part of the bulletin. The values for the percentage of extraction on the area basis are slightly higher than they would be if computed from tonnage produced because of the waste in mining and the presence of slips and horse backs. If these losses did not exist, the values of the percentage of extraction obtained by the two methods would be the same, because the entire thickness of the coal bed is extracted. A comparison of these two methods in rooms 20 by 210 feet with 12-foot pillars and 16-foot cross-cuts gave an extraction on the basis of tons produced of 61.05 per cent and on the basis of area excavated of 67.28 per cent.

The diagram for total output is irregular, because its shape is determined by that for the number of rooms. This number does not change uniformly with change of width of rooms, but, for each set of dimensions, the number of rooms was selected which was most suitable for working out the 160-acre tract to be developed. The total output is the sum of the tonnage of coal produced in rooms and cross-cuts, and in entries. Since the output from entries varies only with the number of cross entries which in turn is affected by a change in the length of rooms, the total output varies only with the number of rooms or with the output from a room and its cross-cuts. The latter quantity varies regularly with the change of room width, and therefore irregularities in the total output are entirely due to irregularities in the number of rooms. The curve for total output is drawn to a scale which makes its irregularities more prominent than those in the curve for the number of rooms.

Diagram *E* shows the cost per thousand tons for the limited number of items considered. The line drops as that showing total output rises, thus showing that the cost of production decreases as the output from a given area increases.

Diagram *F* shows the saving per thousand tons accomplished by increasing the width of room cross-cuts from 8 feet to 16 feet, and eliminating room cross-cut yardage. Mr. Quade's computations were made with the object of determining this saving, and the adoption of the dimensions indicated by these calculations as being most economical has resulted in very large reduction in the cost of producing coal.

The dimensions selected were: room width 24 feet, pillar width 8 feet, cross-cut width 16 feet. The diagrams show that the cost would be lower and the extraction higher if narrower pillars could be used, but it was not practical to make them less than about 8 feet in width. This width is, however, necessary only near the entries; the pillars are made gradually narrower towards the ends of the rooms, the percentage of extraction being thus increased. The extraction in these mines since the adoption of the new dimensions is between 70 and 75 per cent.

For purposes of comparison one set of diagrams is given which shows, for 180-foot rooms, the same items of production and cost as are given for 210-foot rooms. At the time when the computations were made rooms were being driven 180 feet long. The total output for the two lengths of rooms differs only slightly, but the cost of production is lower with the 210-foot room; hence that length was adopted as a standard.

The diagrams in Fig. 14 show the production of coal from different parts of the workings and emphasize the increase of production with increase of room width. Diagram *A* shows the production from rooms and 8-foot cross-cuts. Diagram *B* shows the sum of the tonnage of room and cross-cut coal and entry coal, the space between *A* and *B* representing the entry coal. The space between *B* and *C* shows the additional coal taken from 16-foot cross-cuts; therefore *C* shows the total coal produced from 160 acres with the longer dimension.

Fig. 15 is a graphical summary of costs and output for rooms 24 feet wide and 210 feet long. Diagrams *A*, *B*, *C*, and *D* show the effect of increase of pillar width on the tonnage produced. On these diagrams, *A* shows the number of rooms in 160 acres; *B* shows the output from rooms and 8-foot cross-cuts; *C* shows the additional output from entries; and *D* shows the additional output from the extra width of room cross-cuts. The diagram shows the decrease of output resulting from the decrease in the number of rooms, which accompanies increase of pillar width.

The items of cost considered in the investigation are shown in zones, of which the first is yardage cost for the main entry, the second yardage cost for the cross entries, the third track-laying cost for entries, the fourth brushing and timbering costs for entries, the fifth fixed room charges, and the sixth yardage cost of 8-foot room cross-cuts.

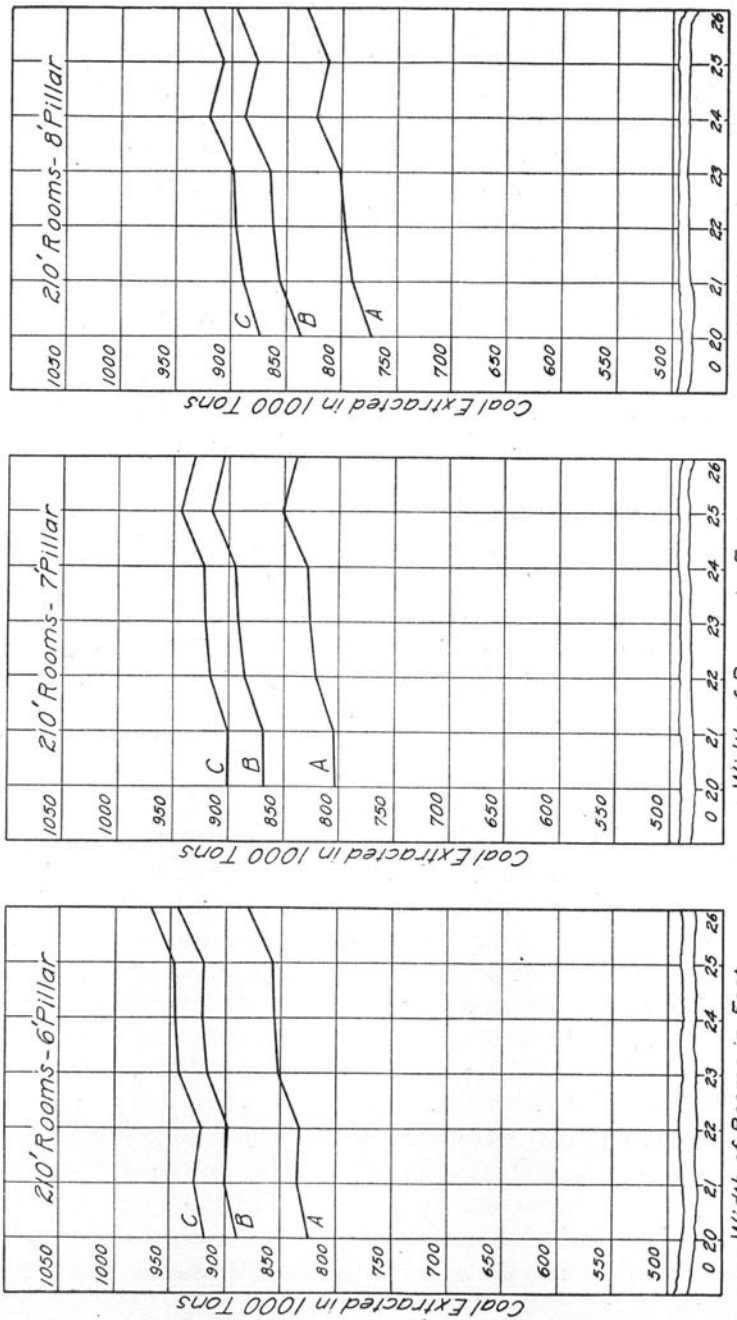

FIG. 14. PRODUCTION FROM ROOMS, ENTRIES, AND FROM ADDITIONAL CROSS-CUT WIDTH

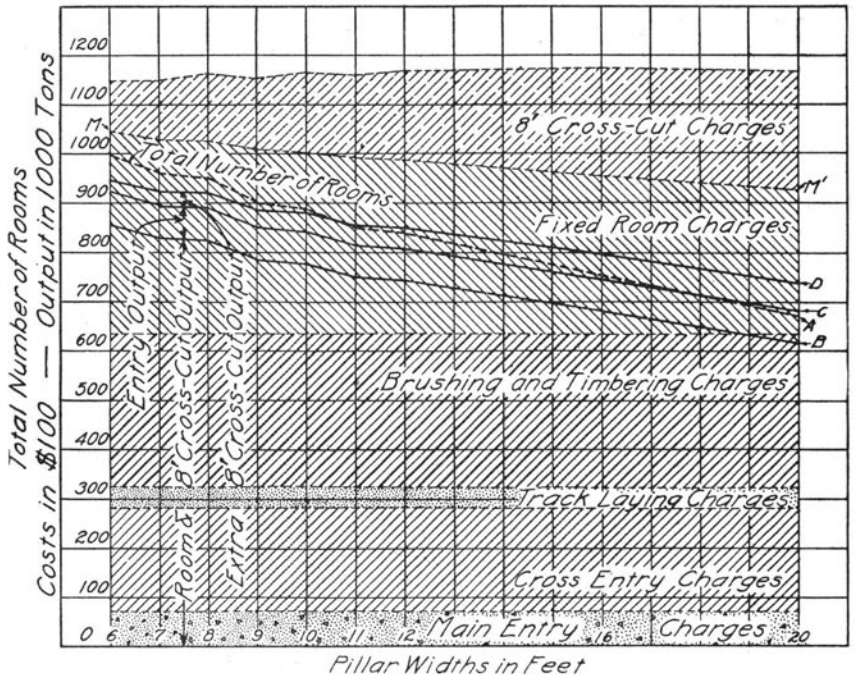

FIG. 15. SUMMARY OF COSTS AND OUTPUT FOR ROOMS 24 FEET WIDE AND 210 FEET LONG

The first four items change only when change in the length of rooms results in change of number of cross entries and therefore of total length of entries. The fifth item, fixed room charges, includes room turning, switch laying and ties, wood rails, and room props. The first three subdivisions change only with the number of rooms; the last increases with the width of rooms but decreases with their number. The sixth item, yardage cost of 8-foot cross-cuts, increases with pillar width because of the increased length of the cross-cuts. It is this last item of cost which is eliminated by increase of cross-cut width to 16 feet, leaving the line M M′ as the indication of total cost.

Some of the charts prepared by Mr. Quade are reproduced with some modification in Figs. 16, 17, and 18 to show more fully his method of presenting his conclusions.

Fig. 16 shows the effect of changes in cross-cut width on yardage cost for room cross-cuts and the amount of coal produced from

them. The diagrams are based on 7-foot pillars with three cross-cuts per pillar. The arrangements of cross-cut widths in each pillar are: three 8 feet wide; one 8 feet and two 12 feet; three 12 feet; one 8 feet, one 12 feet, and one 16 feet; two 12 feet and one 16 feet; one 12 feet and two 16 feet, and three 16 feet. In the final computation of possible reductions of cost the only widths considered were 8 feet and 16 feet.

Fig. 17 gives in detail the cost per thousand tons as modified by certain changes in length and width of rooms, room pillars, entries, and room and entry cross-cuts.

The width of rooms considered, 25.36 feet, was the actual average made by 8 cuts of a breast-type chain coal cutting machine. This machine is commonly called a 3-foot machine, but the actual cut slightly exceeded this width. The costs of the various items considered are shown by the widths of the shaded bands, while the solid line *A B* shows the saving per thousand tons accomplished by the use of the

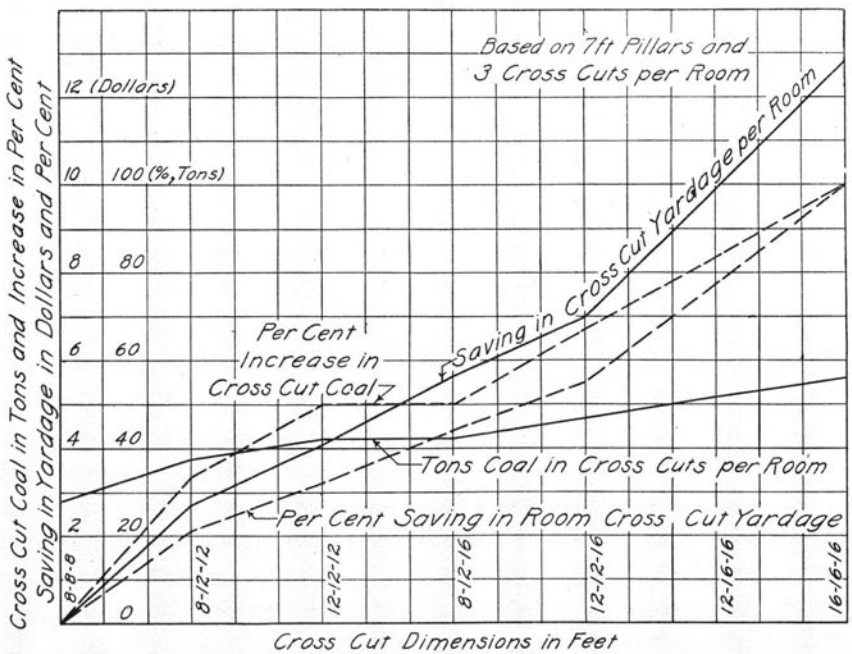

FIG. 16. EFFECT OF CHANGES IN CROSS-CUT WIDTH ON COST OF CROSS-CUTS AND COAL PRODUCED

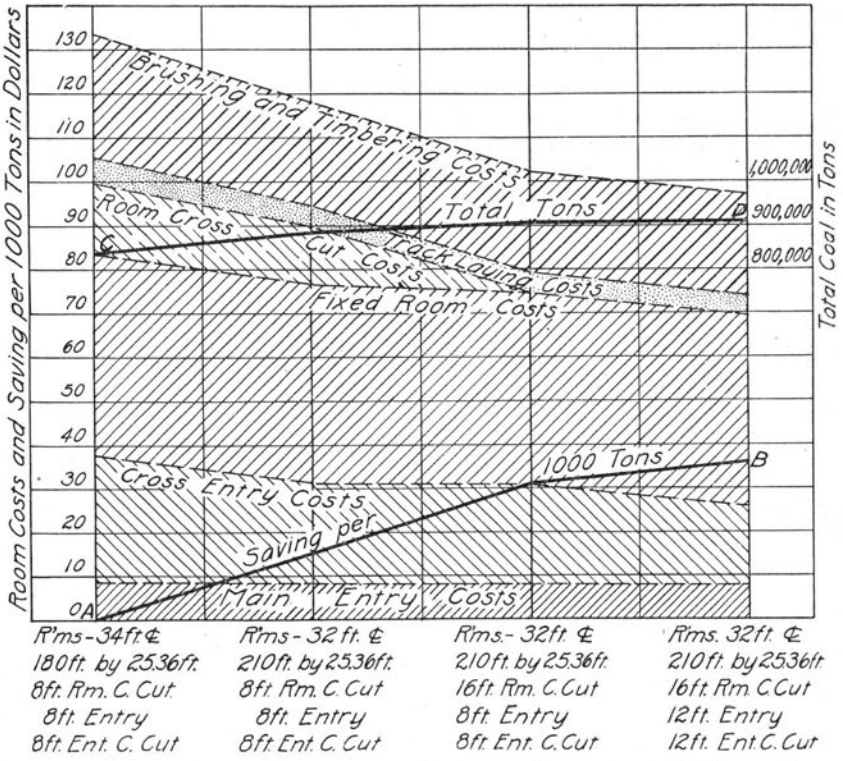

FIG. 17. CERTAIN FIXED CHARGES PER 1000 TONS, SAVING PER 1000 TONS, TOTAL OUTPUT FROM 160 ACRES

different changes in dimensions specified. The solid line *C D* shows the total coal produced from 160 acres with the same dimensions.

Fig. 18 is a summation of the items of room and room cross-cut costs considered and of total extraction and cost for 160 acres. This figure permits comparisons between results obtained by using different dimensions and shows the point of lowest cost and highest extraction. As in Fig. 14, room widths of 22.2 feet and 25.36 feet are due to the width of cut of the breast-type of coal cutting machines. The lower shaded areas show the cost per room for the various items considered as fixed room charges. Room turning and switch costs per room are not affected by any changes of dimensions. Wood rail cost increases with the length of rooms. Prop cost increases with both length and width of rooms. Cross-cut yardage cost is affected by room length,

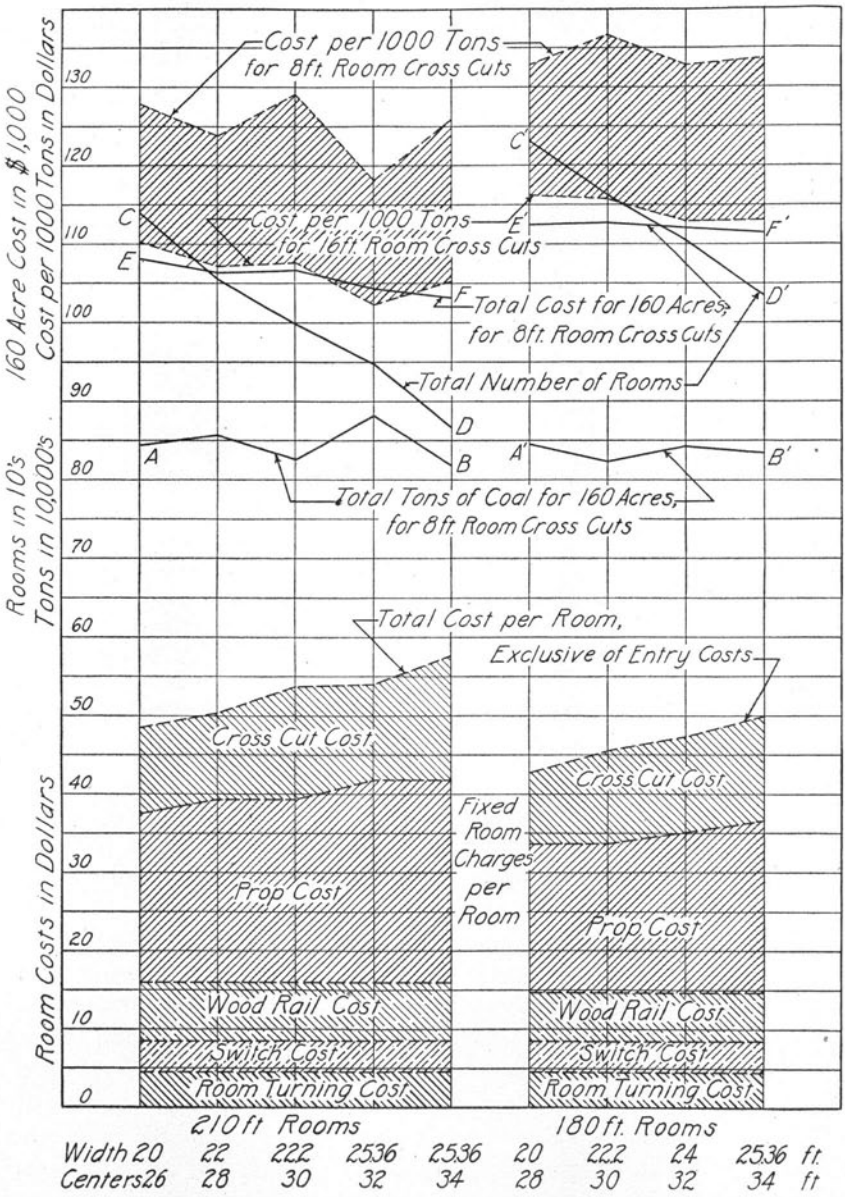

FIG. 18. SUMMATION OF FIXED CHARGES AND OUTPUT FOR 160 ACRES

which determines the number of cross-cuts, by cross-cut width and pillar width. The upper shaded areas show the difference in total cost per thousand tons, including entry costs, which results from the use of 8-foot and 16-foot room cross-cuts. The solid lines *A B* and *A′B′* show the total coal produced from 160 acres; *C D* and *C′D′* show the number of rooms in 160 acres; *EF* and *E′ F′* show the total cost for 160 acres when 8-foot cross-cuts are used.

The lowest total cost for 160 acres is shown to be reached with 210-foot rooms 25.36 feet wide on 34-foot centers, but the lowest cost per thousand tons and the highest extraction for 160 acres are shown to be reached with rooms of the same dimensions on 32-foot centers. Because of the common tendency of the miner to make his room somewhat wider than is planned, the latter dimensions might be approximately reached in practice if rooms were planned 24 feet wide on 32-foot centers. These dimensions, shown by Mr. Quade's work to be the best, were adopted for the company's mines in Fulton County with the result that the cost of producing coal was materially reduced. The percentage of extraction was raised from about 58 per cent to between 70 and 75 per cent which is unusually high for Illinois.

APPENDIX II

Extraction at Dewmaine

Work of G. E. Lyman

The results obtained with different dimensions of rooms in the Williamson County mines of the Madison Coal Corporation are shown in the following sketch and notes prepared by G. E. Lyman, formerly Chief Engineer and now General Superintendent of that company, and are published here with his courteous permission. The sketch, Fig. 19, shows the plan of operation followed at Dewmaine, north of Carterville. The only changes from the dimensions shown are in the width of room pillars, the two widths being 20 feet and 14 feet. The plans considered and compared, with each pillar width, involve the extraction of different quantities of pillar coal after the rooms have been finished.

The area considered is a restricted one, consisting only of a cross entry and a portion of the rooms turned from it. The tract con-

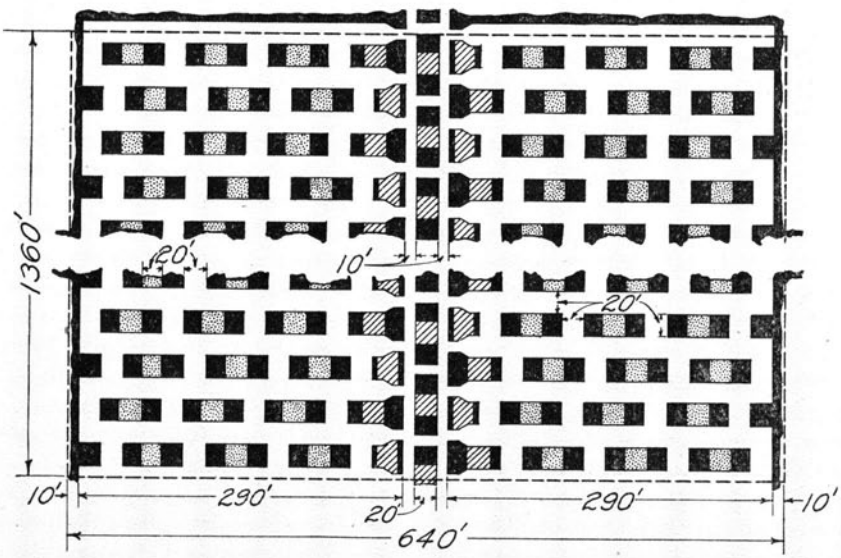

Fig. 19. Dimensions of Rooms and Cross Entries at Dewmaine

sidered is 640 feet wide by 1360 feet long and has an area of 870,000 square feet.

The following notes give the results of experience with different dimensions of rooms and the extraction of different amounts of pillar coal. With each of the two pillar widths different amounts of coal were extracted. With rooms 20 feet wide on 40-foot centers, plan No. 1, shown in white, gave the following extractions:

		Square feet
Rooms		68×5725=389,300
Cross-cuts		4×68× 400=108,800
Entries		2×10×1360= 27,200
Entry cross-cuts		21× 200= 4,200
Total area excavated	(60.7 per cent)	529,500

The experience of the company thus far indicates that workings with these dimensions will stand indefinitely except where soft mud or quicksand predominates in the cover.

Plan No. 2 involves the driving of additional cross-cuts in the room pillars after the room has been completed. These additional cross-cuts are shown by the dotted areas in the figure. The additional area extracted is:

3×68×400=81,600 square feet

Total area excavated	(70.2 per cent)	611,100

Experience indicates that squeezing will occur in rooms, but that the entry stumps will protect the entry so that it will not be closed. More or less water will follow the squeeze. The surface will subside gently to a depth of 2 feet to 4 feet in the center of the area.

Plan No. 3 involves the driving of additional cross-cuts in the room stumps and chain pillar, while retreating, as shown by the hatched areas. The additional area excavated is:

		Square feet
Room cross-cuts	68 feet×400 feet=	27,200
Entry cross-cuts	20 feet×400 feet=	8,000
Total area excavated	(72.4 per cent)	646,300

The results, as far as subsidences are concerned, are practically the same as those obtained by following plan No. 2, except that the entry is closed by the squeeze and more water enters the mine. The surface subsidence is practically the same as in plan No. 2.

Plans Nos. 4, 5, and 6 apply to the same method of working, but with room pillars only 14 feet wide which make 80 rooms in a block 640 feet by 1360 feet.

Plan No. 4 involves excavation of the following areas:

	Square feet
Rooms	$80 \times 5725 = 458{,}000$
Room cross-cuts	$80 \times 4 \times 280 = 89{,}600$
Entries	$2 \times 10 \times 1360 = 27{,}200$
Entry cross-cuts	$21 \times 200 = 4{,}200$
Total area excavated	(66.5 per cent) 579,000

When this plan is followed, squeezing occurs in a room a few months after the first working and more or less water enters the mine. The surface subsidence is about the same as in plan No. 2.

Plan No. 5 involves the driving of additional cross-cuts, as in plan No. 2, and the additional area excavated is:

	Square feet
Cross-cuts	$3 \times 80 \times 280 = 67{,}200$
Total area excavated	(74.2 per cent) 646,200

The results are practically the same as those obtained by following plan No. 2, except that more water enters the mine and the subsidence of the surface is deeper.

When additional cross-cuts are driven in room and entry retreating, as shown by the hatched areas, in plan No. 6, the additional areas excavated are:

	Square feet
Room cross-cuts	80 feet $\times$ 280 feet = 22,400
Entry cross-cuts	20 feet $\times$ 400 feet = 8,000
Total area excavated	(77.7 per cent) 676,600

In this case the entire area squeezes, and a large quantity of water enters the mine. The surface subsidence extends over the whole area and is greater than with any of the other plans.

In the Dewmaine fields it has not been found practical to apply any plan except No. 1 until a considerable portion of the mine is ready for abandonment. Slight changes in the projection, however, are made when changes in physical conditions make them

advisable. Rooms are driven 20 feet wide, but pillars are sometimes reduced to 18 feet and entries are made either 10 or 12 feet wide.

In this field a great deal of trouble has been caused by the entry of water whenever the extraction of too much coal disturbed the overlying strata. Since plan No. 1 alone permits the indefinite sustaining of the overlying material, it is the only one which can be followed without entailing a great expense for handling water. Extraction is therefore limited to about 60 per cent of the panels or blocks, and must be considerably less when considering the whole mine. The calculated percentages of extraction given on page 34 for rooms and pillars of the same ratio of width,— namely, 25-foot rooms with 25-foot pillars, indicate that the total extraction is about 10 per cent less than the extraction in the panel area. It is therefore probable that the total amount of coal extracted in the mine as a whole is about 50 per cent. At various times plans No. 2 and No. 3 have been tried in limited areas, but trouble has always been caused by squeezes and inflow of water.

At the present time mining at No. 8 has proceeded far enough to permit the application of plan No. 3 in working from the boundary toward the shaft. The additional recovery will probably make the total extraction for the entire mine about 60 per cent.

Mr. Lyman points out that both the depth of cover and the nature of the ground vary considerably within short distances in the district referred to and that different results might be obtained within a short distance of the mine mentioned.

APPENDIX III

Work of J. C. Gibson

J. C. Gibson of the Standard Engineering Company of Duquoin has developed a method for calculating the percentage of extraction and the future life of a mine by which it is possible to indicate the parts of the workings in which the losses occur. The following description of procedure is published through the courtesy of Mr. Gibson.

When this method is applied, a tracing of the workings is made showing the outlines of groups of rooms, entries, barrier pillars, and lost areas. In the tracing these separate portions are given distinctive colors in order to prevent any possible confusion. Each area is then measured. This measurement can best be done with a planimeter, but very close approximation to the correct areas can be attained by measuring with a scale, especially if the outlines are not very irregular.

The application of this method to a part of a mine is shown in Fig. 20. The sums of the areas of the different portions in the entire mine are as follows:

Areas worked out (Acres)		*Percentage of Total Area*
Rooms and pillars	157.16	59.76
Entries	62.40	23.73
Lost coal	3.44	1.30
Barriers	40.00	15.21
Total area covered by workings, with exception of the shaft pillar	263.00	100.00

	Tons
Room coal produced	1,421,023
Entry coal produced	378,744
Total coal produced, not including coal taken from the shaft pillar in driving the bottom	1,799,767

The tonnage produced from entries was calculated from the length, width and height of the entries and the weight of the coal per cubic foot, a method permissible when entries are driven with

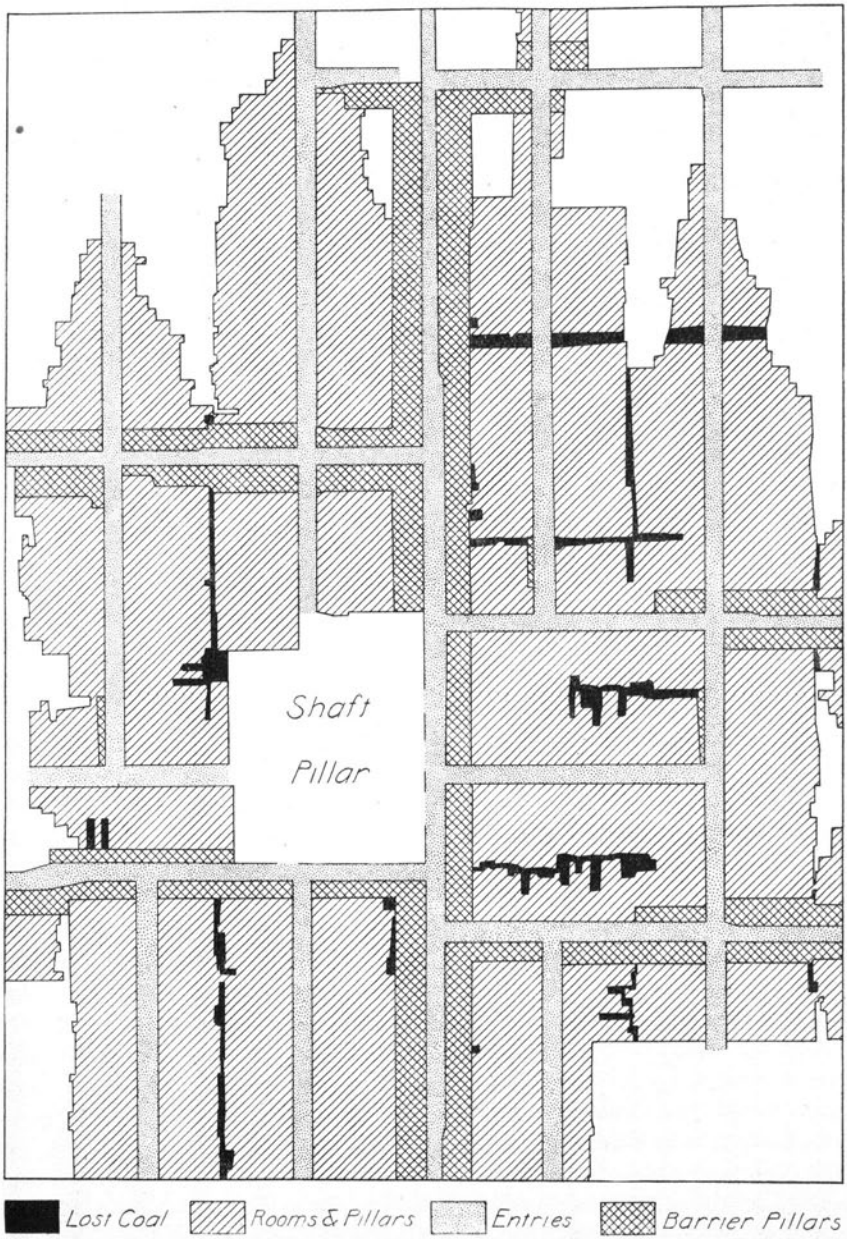

FIG. 20. PORTION OF MINE AS MAPPED BY J. C. GIBSON

careful adherence to the projected dimensions. The tonnage produced from other workings is the difference between total output and entry coal.

The average thickness of coal being 9.4 feet and the weight per cubic foot 81.25 pounds, the amount of coal originally present per acre was

$$\frac{43{,}560 \times 9.4 \times 81.25}{2{,}000} = 16{,}634 \text{ tons}$$

The area worked over by rooms and pillars is 157.16 acres. The coal originally present in the room and pillar area was $157.16 \times 16{,}634 = 2{,}614{,}199$ tons; and the percentage of extraction in the territory occupied by rooms and pillars was

$$\frac{1{,}421{,}023 \times 100}{2{,}614{,}199} = 54.36 \text{ per cent}$$

The entries occupied 62.40 acres, and the coal originally present was $62.40 \times 16{,}634 = 1{,}037{,}961$ tons. The percentage of extraction in territory occupied by entries was

$$\frac{378{,}744 \times 100}{1{,}037{,}961} = 36.49 \text{ per cent}$$

The coal originally present in the whole area was $263 \times 16{,}634 = 4{,}374{,}742$ tons and the percentage of extraction over the whole area worked out was

$$\frac{1{,}799{,}767 \times 100}{4{,}374{,}742} = 41.14 \text{ per cent}$$

Since the thickness of the bed is 9.4 feet and the height of entries only 7 feet, the percentage of area excavated in entries is $\frac{9.4}{7}$ of the percentage of coal extracted.

$$\frac{9.4}{7} \times 36.49 \text{ per cent} = 49.00 \text{ per cent}$$

The data given do not provide a basis for the calculation of percentage of area worked out in the room-and-pillar blocks, because some of the top coal was taken. If no top coal had been taken, the

percentage of area worked out in the seven feet of coal being mined would be equal to the percentage of coal produced from that seven feet. The amount of coal originally present in the areas occupied by rooms and pillars in a thickness of seven feet was

$$\frac{43{,}560 \times 7 \times 81.25 \times 157.16}{2000} = 1{,}946{,}799 \text{ tons}$$

As the coal taken out from these areas was 1,421,023 tons, the percentage of area excavated would have been 73.0 per cent if a thickness of only seven feet had been worked.

$$\frac{1{,}421{,}023 \times 100}{1{,}946{,}799} = 73.0 \text{ per cent}$$

If all the top coal had been taken down to a height of 9.4 feet, the percentage of area worked out would be the same as the percentage of coal produced when the thickness of 9.4 feet is considered, —that is, 54.36 per cent. Since some top coal was left, the percentage of area worked out must have been greater than 54.36 per cent and less than 72.2 per cent in order to give this percentage of extraction; however there are no data from which accurately to calculate the percentage.

In some mines where the only "solid" coal produced is top coal, all the remainder being known as "machine" coal, it would be possible to get from the books of the coal company the number of tons of solid coal paid for,—that is, the top coal. Then the percentage of area worked out in rooms could be determined from the tonnage produced.

It is claimed by Mr. Gibson that given the data on a number of mines in the preceding form, comparisons may be made and possibly much valuable information obtained. For example, mines in which a high percentage of extraction had been obtained in the room-and-pillar areas would indicate the practice to be followed in planning a new operation, provided, of course, that the history of those mines showed their practice to be satisfactory; mines in which the smallest percentage of coal had been lost in barrier pillars, provided the barriers had proved sufficient, would indicate the dimensions of barriers for use in new operations; and mines having the smallest ratio of entry area to room area would suggest efficient methods of developing a property.

Thus, from a number of plans of actual operations, might be developed a composite plan more efficient than any of those studied. It is evident that the two sets of percentages, those of the entire coal seam and those of the number of feet of the seam worked, will enable comparisons to be made with most of the properties studied.

PUBLICATIONS OF THE ILLINOIS COAL MINING INVESTIGATIONS

Bulletin 1. Preliminary Report on Organization and Method of Investigations. 1913. *None available.*

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Bulletin 3. Chemical Study of Illinois Coals, by S. W. Parr. 1916. *Twenty-five cents.*

Bulletin 4. Coal Mining Practice in District VII (Mines in bed 6 in Bond, Clinton, Christian, Macoupin, Madison, Marion, Montgomery, Moultrie, Perry, Randolph, St. Clair, Sangamon, Shelby, and Washington counties), by S. O. Andros. 1914. *Free upon request.*

Bulletin 5. Coal Mining Practice in District I (Longwall), by S. O. Andros. 1914. *None available.*

Bulletin 6. Coal Mining Practice in District V (Mines in bed 5 in Saline and Gallatin counties), by S. O. Andros. 1914. *Free upon request.*

Bulletin 7. Coal Mining Practice in District II (Mines in bed 2 in Jackson County), by S. O. Andros. 1914. *Free upon request.*

Bulletin 8. Coal Mining Practice in District VI (Mines in bed 6 in Franklin, Jackson, Perry, and Williamson counties), by S. O. Andros. 1914. *Free upon request.*

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Bulletin 11. Coal Resources of District VII (Counties listed in Bulletin 4), by Fred H. Kay. 1915. *None available.*

Bulletin 12. Coal Mining Practice in District IV (Mines in bed 5 in Cass, DeWitt, Fulton, Knox, Logan, Macon, Mason, McLean, Menard, Peoria, Sangamon, Schuyler, Tazewell, and Woodford counties), by S. O. Andros. 1915. *Free upon request.*

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Bulletin 100. Engineering Experiment Station, University of Illinois, The Percentage of Extraction of Bituminous Coal, with Special Reference to Illinois Conditions, by C. M. Young. 1917. *Free upon request.*

Bulletin 113. Engineering Experiment Station, University of Illinois, Panel System of Coal Mining, A Graphical Study of Percentages of Extraction, by C. M. Young. 1919. *Free upon request.*

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